DESIGN AND DEVELOPMENT OF CAPACITY CONSTRAINED MPS FOR MRP SYSTEM

A Thesis Submitted
in Partial Fulfilment of the Requirements
for the Degree of

MASTER OF TECHNOLOGY

by

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to the

INDUSTRIAL AND MANAGEMENT ENGINEERING PROGRAMME

INDIAN INSTITUTE OF TECHNOLOGY KANPUR

JUNE, 1988

8. Part-period balancing (PPB)

9. Wagner-Whitin algorithm

10. Modified EOQ

11. Modified least total cost.

For detailed description of these lot sizing techniques, the reader is referred to the classical book on MRP by Orlicky [14].

Wagner-Whitin algorithm is based on dynamic programing approach and yields optimal results. Its disadvantages mentioned in the literature are high computational burden, near impossibility of explaining it to average MRP user and high instability in the planned order schedule.

Each of the lot sizing technique mentioned above is imperfect - each suffers from some deficiencies. The factors that affect the relative effectiveness of the individual lot-sizing techniques are the following :

1. The variability of demand
2. The length of the planning horizon
3. Size of the planning period
4. The ratio of the setup and unit costs.

Orlicky [14] states that actual relative effectiveness of a lot-sizing algorithm can be determined only in retrospect.

DEDICATED TO

MY PARENTS

CHAPTER III

METHODOLOGY FOR THE DEVELOPMENT OF CAPACITY CONSTRAINED M.P.S.

In this chapter the methodology developed for the preparation of the capacity constrained MPS for MRP system is discussed. We present in brief the production system environment for which the methodology adopted is suitable and assumptions made in its development.

3.1 Production System Environment:

The production system under consideration produces a number of products for make to stock market. These products, assembled from several components, have well defined product structure. They do not have optional features at any level of product structure. The product design has been standardised and it does not vary at individual customer's choice.

The basic input to MPS is forecast of demand of each product in all planning periods of the planning horizon. The MPS is described in terms of end items.

The plant layout can be both product type and job shop type. The capacity of a work centre is expressed in terms of man hours or machine hours which ever is critical.

3.2 Assumptions:

Following are the major assumptions made in the development of capacity constrained MPS.

ACKNOWLEDGEMENT

I feel great pleasure in expressing my heartfelt thanks to Dr. J. L. Batra for his expert guidence, valuable suggestions, useful criticism, constant encouragement and moral support extended during the execution of the entire work.

With great pleasure, I acknowledge the constant inspiration from my eldest brother without which I would have not been what I am today.

I like to thank Mr. Anil Agarwal for his elder brotherly advice and moral support.

I would like to thank all my friends who made my stay at I.I.T. Kanpur a pleasant and memorable one. In particular, I would like to thank Kishan, Sanjeeb, Sanjay and Somesh.

Surendra Kumar Gupta

Example :

Input Data:

$T_j = 150$

$B_j = 25$

$Q_j = 10.$

Period	1	2	3	4	5	6	7	8
D_{jk}	100	150	80	200	300	100	100	150

Iteration 1:

step 1:

A_{jk}	150	150	150	150	150	150	150	150

step 2 & 3:

I_{jk}	65	65	135	85	-65	50	100	100

step 4: $X=6$, $Min(I_{jk}) = 50$, $k = 6$ to 8

step 5:

A_{jk}	150	150	150	150	150	100	150	150

Iteration 2:

Repeating steps 2 to 5 yields following:

$X=7$, $Min(I_{jk}) = 50$ $k = 7$ to 8

A_{jk}	150	150	150	150	150	100	100	150

Iteration 3 :

Repeating steps 2 to 5 yields following:

$X=8$, $X = K$, and $Min(I_{jk}) = 0$ $k = 8$

A_{jk}	150	150	150	150	150	100	100	150

inventory etc. This file is kept up to date by posting of inventory transactions.

The primary outputs of an MRP system are as follows.

1. Order release notices, calling for the placement of planned orders.

2. List of planned orders scheduled for release in the future.

3. Rescheduling notices, calling for the changes in the open order due dates.

4. Item status analysis.

5. All the information necessary for the development of a closed-loop MRP system through Capacity Requirements Planning (CRP).

3.8.3. MRP Processing

3.8.3.1 Quantity Conversion

Demand for an item is usually available for a planning period, but MRP system requires time bucket wise demand. The length of a planning period is usually greater than that of a time bucket. For example planning period can be a month or a quarter and time bucket can be a day or a week. For converting this quantity the method followed here is called ' Work Day Approach ' [10]. It determines the production rate per day and then multiplies it by the number of working days in the time bucket to obtain the demand in that time bucket. This conversion is based on the calender of factory. It contains the number of working days in each planning period and the time bucket period.

CERTIFICATE

Certified that the work on " DESIGN AND DEVELOPMENT OF CAPACITY CONSTRAINED MPS FOR MRP SYSTEM ", by Mr. S. K. GUPTA, has been carried out under my supervision and it has not been submitted elsewhere for the award of a degree.

(J. L. Batra)

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ABSTRACT

Material Requirement Planning (MRP) has undergone considerable devalopments since its inception in 1960's. In 1970's the concept of " Closed Loop MRP " was developed. It integrates MRP with master production scheduling and capacity requirement planning (CRP). For the effective use of an MRP system development of capacity constrained MPS (CCMPS) is very important. In the present work a system has been designed and developed for this purpose. The proposed system involves four basic modules. The four basic modules of CCMPS, viz., Resource Requirement Planning, Rough Cut Capacity Planning, Material Requirement Planning and Capacity Requirement Planning have been developed and implemented. The system takes demand forecast, product structure and resource requirement on various work centres for each product as the basic inputs. A methodology has been developed to generate a feasible production schedule. The feasible production schedule is further processed through the MRP logic to generate time phased material plan of each item/component. The capacity requirement planning module further generates time phased capacity requirements at each work centre for the developed material plan.

Various lot sizing policies have been incorporated in the CCMPS system to schedule planned orders for each item/component. Alternate MPS plans and capacity plans can be generated by changing the shop load factor supplied at rough cut capacity planning level and lot sizing tachnique applied to each

CHAPTER IV

DETAILS OF IMPLEMENTATION

In this chapter, we discuss the implementation of the CCMPS methodology presented in the previous chapter.

4.1. Elements of System Code:

All the four modules of CCMPS described in chapter III have been implemented using Turbo Pascal Version 3.01 on PC XT/AT. Pascal is used because it has strong data structure facility and long programs can be easily understood and debugged. Moreover, the compiled version of the program can be run on Disk Operating System (DOS) without using any system files. This makes it faster than if the program were written in any other interpretter based programming languages like Basica, dBase III^{+} .

4.2 Design Features:

As pointed out in chapter III, the development of MPS is basically a hierarchical decision making process. Each module of CCMPS, viz., resource requirement planning, rough cut capacity planning, MRP process, and capacity requirement planning can be run separately. However, these models should be run in proper order. If the system is not run in proper order then either the system will halt or will produce wrong results. If the results at any stage are not acceptable, the system can be rerun from

Scope For Further Work:

1. The preparation of MPS, basically starts from aggregate planning of resources. The present work can be extended to incorporate it.

2. The proposed system does not consider the cost implications of the developed MPS. System can be extended to include inventory cost data for the optimal selection of lot sizing policy for each item component.

3. The work centre capacity is considered inflexible. The capability of the system could be further enhanced by incorporating the work centre capacity changes through overtime etc.

4. In the present work the " What-if " capability of MRP system entails reprocessing of the entire MPS. This could be modified so that only the changes in the master schedule are processed rather than exploding the entire MPS.

ABSTRACT

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Various lot sizing policies have been incorporated in the CCMPS system to schedule planned orders for each item/component. Alternate MPS plans and capacity plans can be generated by changing the shop load factor supplied at rough cut capacity planning level and lot sizing tachnique applied to each

Factory Calender :

Current Planning Period : 1
Current Time Bucket : 1

Planning Period:

No. :	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Total Working Days:	22	23	21	23	21	20	18	19	22	23	21	19	18	21

Time Bucket:

No. :	1	2	3	4	5	6	7	8	9	10	11	12	14	15
Total Working Days:	5	5	5	5	5	5	4	4	5	3	4	4	5	5

No. :	16	17	18	19	20	21	22	23	24
Total Working Days	5	5	4	5	3	4	5	5	5

With above data the system is run for to get capacity constrain ed MPS. The results obtained are as follows:

Resource Requirement Planning:

Shop Load Limit Factor : 0.85

Over Load Work Centres :

W.C. Code	Available M/C's	Required M/C's
M5	14	15

Under Load Work Centres :

W.C. Code	Available M/C's	Required M/C's
M2	10	3
M3	11	9
M4	11	9

item/component.

Facility has been provided for the graphical display of period wise capacity required vs capacity available for various work centres. It helps in evaluating capacity plans.

The CCMPS system has been implemented using Turbo Pascal version 3.01 on PC XT/AT.

TABLE V

Item code:BABS   Lead time: 2   Beginning inventory: 100
Safety stock: 10   Lot size: Lot for Lot

Period:	1	2	3	4	5	6	7	8	9	10	11
Gross:	1473	1473	987	1470	1272	789	1470	1074	792	0	0
Sch.Recpts:	0	0	0	0	0	0	0	0	0	0	0
Net:	1383	1473	987	1470	1272	789	1470	1074	792	0	0
Plan Recpts:	1383	1473	987	1470	1272	789	1470	1074	792	0	0
Ending Inv.:	0	0	0	0	0	0	0	0	0	0	0
Ord.Release:	987	1470	1272	789	1470	1074	792	0	0	0	0

Total cost of ordering and inventory carrying : 8750.00

Orders to be expedited :
An order of 1383 to be released in period -2 for requirement in period
An order of 1473 to be released in period -1 for requirement in period

press RETURN to continue.......

TABLE VI

Item code:BACS   Lead time: 1   Beginning inventory: 100
Safety stock: 7   Lot size: Modified LTC

Period:	1	2	3	4	5	6	7	8	9	10	11
Gross:	966	966	0	966	966	0	966	966	0	0	0
Sch.Recpts:	0	0	0	0	0	0	0	0	0	0	0
Net:	873	966	0	966	966	0	966	966	0	0	0
Plan Recpts:	873	966	0	966	966	0	966	966	0	0	0
Ending Inv.:	0	0	0	0	0	0	0	0	0	0	0
Ord.Release:	966	0	966	966	0	966	966	0	0	0	0

Total cost of ordering and inventory carrying : 250.00

Orders to be expedited :
An order of 873 to be released in period -1 for requirement in period 1

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CONTENTS

TABLE XV

Item code:AACE   Lead time: 1   Beginning inventory: 300
Safety stock: 100   Lot size: Lot for Lot

Period:	1	2	3	4	5	6	7	8	9	10	11
Gross:	343	343	343	343	342	343	274	274	343	205	274
Sch.Recpts:	0	0	0	0	0	0	0	0	0	0	0
Net:	143	343	343	343	342	343	274	274	343	205	274
Plan Recpts:	143	343	343	343	342	343	274	274	343	205	274
Ending Inv.:	0	0	0	0	0	0	0	0	0	0	0
Ord.Release:	343	343	343	342	343	274	274	343	205	274	0

Total cost of ordering and inventory carrying : 6500.00

Orders to be expedited :
An order of 143 to be released in period -1 for requirement in peric

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TABLE XVI

Item code:BAAS   Lead time: 1   Beginning inventory: 100
Safety stock: 10   Lot size: Lot for Lot

Period:	1	2	3	4	5	6	7	8	9	10	11
Gross:	1623	1623	1621	1618	1489	1297	1429	1357	1104	771	0
Sch.Recpts:	0	0	0	0	0	0	0	0	0	0	0
Net:	1533	1623	1621	1618	1489	1297	1429	1357	1104	771	0
Plan Recpts:	1533	1623	1621	1618	1489	1297	1429	1357	1104	771	0
Ending Inv.:	0	0	0	0	0	0	0	0	0	0	0
Ord.Release:	1623	1621	1618	1489	1297	1429	1357	1104	771	0	0

Total cost of ordering and inventory carrying : 4050.00

Orders to be expedited :
An order of 1533 to be released in period -1 for requirement in perio

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CHAPTER I

INTRODUCTION

1.1 Material Requirement Planning:

Material Requirement Planning (MRP) System is a computer based approach to scheduling production and managing inventories where the decisions are linked in a very productive way. Basically an MRP system is a set of logically related procedures of decision rules and records designed to translate a Master Production Schedule (MPS) into time phased net requirements and the planned coverage of such requirements for each component inventory item needed to implement this schedule. MPS outlines the production plan for all end items.

The management objectives of MRP are to provide " right part at right time " to meet schedule for completed products. To achieve this, MRP time phases requirements, generates lower level requirements, releases planned orders and reschedules the planned orders. Time phasing of requirements simply establishes the time period in which the work must be accomplished to meet delivery dates of the end items as stipulated in the MPS. Planned order releases indicate when order should be placed for purchasing and manufacturing. When work cannot be accomplished on time MRP can reschedule planned orders. Accomplishing these plans without excess inventory, overtime, labour or other

resources is also important. Therefore, the MRP ensures that the planning is integrated, i.e., that the correct number of components for each end item, raw material for each component and so on is planned for each part number.

There is a basic difference in the application of traditional inventory control techniques and MRP. MRP system is appropiate for dependent demand items. Demand for an item may be independent or dependent. Independent means no relationship exists between the demand for an item and any other item, such as a product. Independent demand tends to be continuous and fluctuates because of random influences. In contrast, dependent means the demand for an item is directly related to or results from the demand for a higher level item. Dependent demand is not random but tends to occur in a lumpy manner at specific point in time. The lumpiness occurs because most manufacturing is in lots and all the items needed to produce the lot are usually withdrawn from inventory at the same time, not unit by unit. Thus although the demand for the final product may be continuous and independent, the demand for the lower level items composing the product tends to be discrete, derived and dependent. Dependent demand items need not be forecasted, but can be calculated by the MRP system from MPS. In manufacturing organisation most inventory items are dependent and should be controlled by the MRP system.

The effectiveness of an MRP system lies in the attainment of the following objectives concurrently.

1. Ensure the availability of materials, components and products for customer delivery.

2. Maintain the lowest possible level of inventory.

3. Plan manufacturing activities, delivery schedules and purchase schedules.

1.2 Importance Of Feasible MPS :

A Master Production Schedule (MPS) is a statement of requirement for end items by dates (planning period) and quantity [10]. MPS is typically one of the three principal inputs to the MRP system. But whereas the other two i.e inventory status and product structure supply reference data to MRP process, the MPS constitutes the input that drives it. Thus, MPS is the prime input on which MRP system depends for its real effectiveness and usefulness.

In managing the MPS and in using it to manage inventories and production the following basic law should always be observed.

" The MPS should be a statement of what can and will be produced rather than what management wishes and had been produced in the past and/or would like to be able to produce in immediate future "[22].

Decisions are dictated through MPS at various levels of management and it relates to and involves many company personnel. Top management wants to review planned production against production targets. They also want to have a long term review of when existing labour and machining capacity will be

exceeded. Operation management would like to know in advance when overtime or an extra shift is required to meet demand. Inventory management wants to see the impact of planned production against the anticipated demand on the level of inventory, period by period. Purchasing would like to be aware of those long lead times that are required to avoid missing potential customer orders in future. Marketing would like to make valid customer delivery date promises. Thus inventory management action, procurement action and manufacturing action, all these are directly or indirectly dictated by the contents of Master Production Schedule. In fact a MPS should not only be feasible but must understand the realities of the manufacturing floor. The MPS should be feasible in three ways; viz, availability of :

- Material
- Time
- Production capacity.

Each one of them is equally important. A lack of critical material or lead time or capacity precludes production - and if MPS insists on such production it will incapacitate the MRP system in its priority planning function, leading to collapse of shop priority system. The manufacturing organisation then reverts to form: staging, stockouts, assembly shortages, hot lists, expediting and confusion which results in increase of manufacturing costs. In such circumstances, the informal system takes over because the formal system of which the MPS is a critical part is not doing its job.

An important feature of capacity constrained MPS is the generation of feasible capacity requirement plan for the work centres. This function is concerned with how to get the production built (with available resources) or more specifically how to schedule these work centres that typically cause bottleneck problems. Without the provision of adequate capacity or recognition of the existance of excess capacity, the benefits of an otherwise effective MPS cannot be fully realised. On one hand insufficient capacity will lead to deteriorating delivery performance, escalating work-in-process (WIP) and frustrated manufacturing personnel, who will quickly turn back to informal system to solve the problems. On the other hand excess capacity is needless expense that can be reduced.

It needs to be pointed out that an MRP system is capacity insensitive. It will process the MPS through its logic without checking whether the plan is feasible on manufacturing shopfloor or not. However, by inputting a valid and realistic Master Production Schedule an MRP system can be made to carry out its functions with greater efficacy.

1.3 Hierarchy Of Decisions Involved in Capacity Constraint MPS:

Capacity Planning and Control Study Guide, published by APICS (March, 1975) discusses the following hierarchy of decisions for the preparation of feasible capacity requirement plan (which is the outcome of feasible MPS). Figure 1.1 shows MRP and other modules of an integrated production system. Starting from the overall plan of the resources, proceeding to a rough cut evaluation of capacity implications

of a particular MPS, there after moving to the detailed evaluation of capacity requirements based upon detailed MRP records, continuing to finite loading procedures and ending with input/output technique to help monitor the plan. The basic structure of the decision process as depicted in Fig 1.1, more or less, holds good for most of the manufacturing systems. However, the method of MPS preparation differs from one concern to other and we cannot expect any two firms to have the same process of MPS preparation.

1.3.1 Links To Other System Modules:

Resource Requirement process is directly linked to production planning module. This process is highly aggregated and is a long term capacity planning decision.

In figure 1.1, Rough Cut Capacity Planning (RCCP) and Capacity Requirement Planning (CRP) are the other two important components of the capacity planning process. RCCP and CRP are linked with MPS and MRP respectively. The linkages are shown as double headed arrows for a very specific reasons. There must be a correspondence between the capacity required to execute a material plan and that made available to execute the system. If the correspondence does not exist, the plan will either be impossible to execute or inefficiently executed. Either MPS or capacity plan should be changed to make the plan feasible.

Substantially more detailed capacity planning is possible using CRP techniques. CRP generates time phased capacity requirement at various work centres. The data files used by CRP are work-in-process, routing, scheduled receipts, and planned orders.

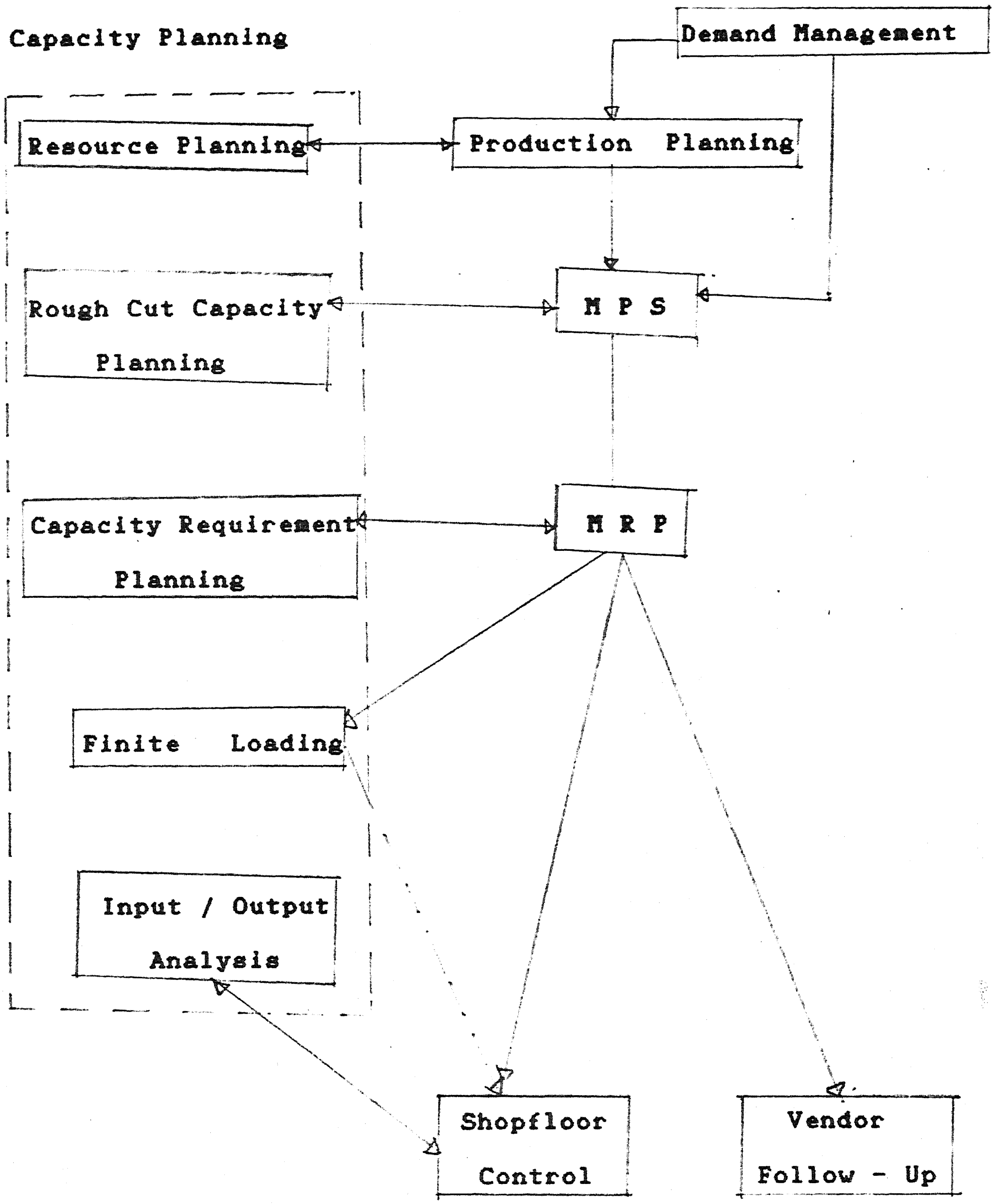


Fig 1.1

Hierarchy Of Decisions Involved In Preparation Of Capacity Constrainted MPS.

The finite loading can be better viewed as shopfloor scheduling technique. Input/output analysis provides a method for monitoring the actual consumption of capacity during the execution of MPS plan.

The primary interaction among the various decision levels discussed above is hierarchial : resource planning sets constraints on short to medium range capacity planning, which in turn constraints detailed scheduling and execution on the shopfloor.

1.4 Objective and Scope of Thesis:

The present work deals with the "Design and Development of Capacity Constrained Master Production Schedule for MRP System". The design and development of such a system involves several hierarchial decisions as depicted in Fig 1.1. A survey of literature indicated that various investigators have developed models and approaches for dealing with the various modules indicated in Fig 1.1. However, there seems to be lack of a systematic approach integrating resource planning, rough cut capacity planning and capacity requirement planning for the generation of a capacity constrained MPS to support the MRP system.

Given the demand forecast of each product over the planning horizon and the product structure along with the product resource requirement profile the resources required at various work centres are calculated to support the average production level of each end product. The required resources are compared with the available

resources and effective production targets are calculated for each product.

Next, the process of production levelling is carried out to generate levelled production schedule for the shopfloor. Such a schedule is referred as 'Perspective MPS' which is further used for the purpose of rough cut capacity planning. The rough cut capacity planning checks the feasibility of perspective MPS on critical work centres. Critical work centres are those which for want of adequate capacity to support the perspective MPS cause bottleneck problems on the shopfloor. At rough cut capacity planning the perspective MPS is further modified to generate period wise feasible production schedule. For this purpose methodology proposed by Sadowski et. al. [18] has been used with certain modifications. The feasible production schedule is translated into time bucket wise schedule to support the MRP system. The conversion process is accomplished through a 'Quantity Conversion Process' for which methodology proposed by Gassner [10] has been used. The time bucket wise schedule developed from the quantity conversion process is termed as ' Authorised MPS'. The authorised MPS is inputted into MRP system to generate the time phased requirement of item/component/raw material. Several lot sizing techniques are incorporated for determining the scheduled planned order requirements. The time phased capacity requirements at each work centre are generated next, using scheduled planned order requirements. This process is referred as Capacity Requirement Planning for which a modified version of the methodology proposed by Vollmann et. al. [22] has been used.

The system designed has been programmed using Turbo Pascal Versin 3.01 and is implemented on PC XT/AT.

1.5 Organisation of Thesis:

In chapter II a brief review of the important literature on MRP, Capacity Constrained MPS and Lot sizing techniques has been discussed.

Chapter III deals with the methodologies developed for the design of the capacity constrained MPS system. The implementation details are presented in chapter IV. The details of the results obtained for a sample problem are given in the form of an appendix.

In chapter V the conclusion of the study are presented along with scope for further work.

CHAPTER II

LITERATURE REVIEW

Lot of literature is available on the wide spectrum of areas with which the present work deals with. A detailed review of literature was undertaken. However, in the following sections, a brief review of the important literature on material requirement planning, capacity constraint MPS and lot sizing techniques used in MRP system is presented.

2.1 Material Requirement Planning System:

Since MRP system demands handling of large amount of data at high speed its growth has paralleled developments in computer technology. Its origin in 1960 was in line with the movement towards the acceptance of quantitave management tools that need the digestive power of computer. Early spokesmen for MRP included G.W. Plossal, J.A. Orlicky and O.W. Wight. The first book on the subject was written by J.A. Orlicky in 1970. The MRP concept were nurtured effectively by the American Production and Inventory Control Society (APICS) in 1960 by what is called MRP crusade.

Several organisations now offer software packages and consulting services for MRP implementation [3]. MRP system for large companies have been developed by large software (or software and hardware) houses which maintain consulting staff to assist firms with implementation. Software for microcomputers have been, to date, developed primarily by smaller firms which

do not have the capability to provide implementation consultation and training. These packages are later customerised to a buyer's needs.

Riggs [16] while quoting Orlicky, suggests that successful MRP user enjoys a reduction in manufacturing inventory investment load of 20% to 30%. Other claimed benefits are in reduction of production and purchasing cost and improved delivery service. However, all MRP implementations have not been successful, and at least one source indicates that proportion of successful MRP system is as low as 5% [1]. While carrying out switch over from traditional inventory control to an MRP system human relation and technical difficulties have to be fraught with. Plossal and Wight [15] state that "... there is tremendous application potential for MRP. There have been a number of highly successful companies and a great number of companies have not really been able to use the tool effectively." Further they point out, "It is easy to see how companies can manage poorily without MRP, but it is hard to see how they can manage well without it."

MRP has gone through many stages in its evolution. In late 1970's Wight and Plossl began to talk about closing the loop in MRP systems. The closed loop MRP system is a system built around material requirement planning and also including the additional planning fuctions of production planning (aggregate planning), master production scheduling and capacity requirement planning. Further, once the planning phase is complete and plan has been accepted as realistic and attainable, the execution functions come into play. These include the shop floor control functions of input-output measurement, detailed scheduling and dispatching. The

term "closed loop" implies that not only are these elements included in the overall system but also that there is feedback from the execution functions so that the planning can be kept valid at all times.

Later MRP evolved into MRP II: Manufacturing Resource Planning. Here also the main contributors were Wight and Plossl. MRP II is a method for the effective planning of the resources of a manufacturing firm. Ideally, it addresses operational planning in units, financial planning in rupees, and has a simulation capability to answer "what if" questions. It is made up of a variety of functions, each linked together: bussiness planning, production planning, master production scheduling, MRP, capacity requirement planning, and even the execution support system for capacity and material. MRP II is a direct outgrowth and extention of closed loop MRP system.

2.1.1 Nervousness In M R P:

The major problem in implementation of MRP system is "Nervousness ", i.e. instability in the MRP plans. The MRP plan can change the quantity and timing of planned orders even though there are not significant changes in the MPS. Several recent papers have examined this important problem of Nervousness in MRP system. Steele [17] has attributed changes in the MPS and dynamic lot sizing as the important contributors of nervousness in MRP system. Berry et al. [2] and Vollmann et al.[22] have suggested that the nervousness of an MRP system can be considerably reduced by freezing the MPS, especially over the cumulative lead time of product. This approach is frequently used

in practice. In a simulation study conducted by Minific and Heard [13], they observed that freezing the MPS has significant effect on MRP nervousness in addition to the lot sizing methods employed. Kropp et al. [11] and Carlson [8] have modified several lot sizing procedures used in rolling planning horizon environments to incorporate the cost of changing MPS, there by alleviating nervousness by considering its economic effects. These procedures suffer from the fact that in practice it is difficult to find the cost of changing MPS.

In another simulation study Sridheranet.al. [19] have compared the effect of freezing planned orders and freezing number of planning periods on nervousness. Their study showed that freezing the number of planned orders gives better results than freezing a certain number of periods. However the results are sensitive to, viz; demand pattern, length of planning horizon, percentage of planning horizon freezed etc.

2.2 Master Production Schedule Planning:

The literature on master production schedule planning has been reviewed separately at strategic level and short term capacity planning level.

2.2.1 MPS Planning At Strategic Level:

At the strategic level the resources required are tested on critical machines which may cause bottleneck problems due to non-availability of adequate production capacity, before feeding the MPS to MRP processor. Vollmann et al. [22] have described several models, viz, 'capacity planning using overall factors ',

'capacity bill' and 'resource profile method' for capacity planning at strategic level.

Capacity planning using overall factors (CPOF) is relatively simple approach to rough cut capacity planning in which the data is obtained from MPS. First it calculates the capacity requirements for the stated production schedule for the overall plant based on the historical data about the man-hour or machine-hour required for each end product. The second step involves using historical ratio to allocate the total capacity required each period to individual work centres. The historical percentage of the total direct labour-hour worked during the prior years is used to determine allocation ratio.

Capacity bill procedure provides a much more direct link between individual end products in the MPS and the capacity required at individual work centres. It takes in to account any shift in product mix. It requires more data than CPOF. Bill of material, routing data and direct labour and machine hour data must be available for each operation for this method. It first involves development of bill of capacity. Bill of capacity indicates the total standard time required to produce one end product in each work center required in its manufacture. Once the bill of capacity for each end product has been prepared, the MPS can be used to estimate the capacity requirements at individual work centers.

Resource profile takes into account specific timing of the projected work load at individual work centres. In developing resource profile production lead time data are taken into account to provide time phased projection of the capacity requirements

for individual production facility. When lead times are large this method gives better results than other methods.

Sadowski et al. [18] have proposed a methodology to aid in the capacity planning effort at the strategic level. A general model is formulated which allows the computation of machine requirements at the end product level. Procedures for elimination of non-key machines, determination of effective production capacity are presented. This methodology needs user's interaction in selecting the product for adjusting the production level if capacity available is inadequate to support the requested production in a period. This methodology has been used in the present work and above deficiency has been taken care by incorporating a priority rule for selecting the product for production level adjustment.

Bernard et al. [4] have developed a methodology for overall analysis of complex production system using Q-GERT network modelling and simulation. Q-GERT is a derivative of GERT network modelling. Q-GERT is suitable as a framework for analysis and not as solution technique. As such it is a model in which solution to individual problem can be explored, tested, and evaluated. The results of the system can be applied to production planning, job design, system design etc.

2.2.2 MPS Planning At Capacity Planning Level:

The major problem in capacity requirement planning is scheduling planned orders so that capacity requirements lie within feasible range. If available capacity is exceeded management can respond by shifting some production or by

changing capacity (add overtime etc). If production is shifted there is a chance that some other capacity problem will be caused at some other production stages / or in some other time period. Furthermore some shift may be preferable to other yielding fewer late deliverie s, less inventory cost or fewer expedited orders. Hence a method for allocating production within available capacity is needed. MRP II system do explicitly include a rough cut capacity planning phase before bill of material (BOM) explosion, but they do not give model based assistance to the manager in the process.

Steinberg and Napier [20] presented an integer programming formulation to the lot sizing problem without work center capacity constraint.

Collier [9] studied the interaction of lot sizing and capacity planning and observed that certain lot sizing techniques could lead to more erratic capacity usage. However, Bellington, McClain, and Thomas [7] claimed that batching may either help or hurt the capacity usage pattern.

Very few results are available on the three way interaction of lead time, lot sizing and actual capacity usage with the complex (generalised) product structure. Bellington et al.[6] have formulated capacity / lot sizing / lead time problem as Mixed Linear Programming problem which they call MRP-ILP. Since an MRP plan is a rolling schedule the size of the problem becomes very large. For want of an efficient method of solving the problem, the approach is not suitable for real life implementation.

Belt [5] in his description of the dilemma of the planning stated that MRP and capacity planning have not been well integrated.

2.3 Lot Sizing:

Lot sizing is used to minimize the sum of setup cost (fixed or ordering cost) and inventory carrying costs. This is, undoubtedly, the best-researched aspect of material requirement planning [14]. Lot sizing techniques have been proposed for single stage and multi stage production system considering capacity limitation, lead time aspects etc. The literature available on lot sizing problems in multi stage production systems with capacity limitation and lead time consideration has already been presented in the previous section.

Karni [12] and Sunderson [21] have proposed heuristics for single stage planning system. Karni has considered single facility capacity constrained problem and has developed a heuristic for solving it while Sunderson has developed two heuristics for multi-facility capacity constrained problem.

The most widely recognised approaches to lot sizing are as follows: [14]

1. Fixed order quantity (FOQ)
2. Economic order quantity (EOQ)
3. Lot for lot (LFL)
4. Fixed period requirement (FPR)
5. Period order quantity (POQ)
6. Least unit cost (LUC)
7. Least total cost (LTC)

The total production requirement placed on the plant is termed as Schedule of Factory Requirements. It goes as an input to Resource Requirement Planning System along with product structure and resource profile for each item/component.

The Resource Requirement Planning (RRP) uses operations data at end item level i.e. it requires standard and setup times for each end item at those work centres where it is processed. These aggregate data are obtained from product structure and resource profile data. RRP constitutes production level target setting, calculation of resources required to support the target production and testing the resources required against resources available.

For initialising RRP system the initial production target for each product is set at the average requirement of the product over the planning horizon, derived from the schedule of the factory requirements. These production targets for each product are tested against resources available. If the resources available are not sufficient then either the production targets or resource available are adjusted to make the production plan feasible. The outputs of RRP are feasible production targets for each end product. The feasible production targets are inputted into production levelling process.

The production levelling process reschedules the production of each product in each period so that production in minimum number of periods deviates from target production level, ensuring that minimum amount of inventory is carried from one period to the next. The output of the production levelling process is termed as Perspective MPS and it is inputted into rough cut capacity

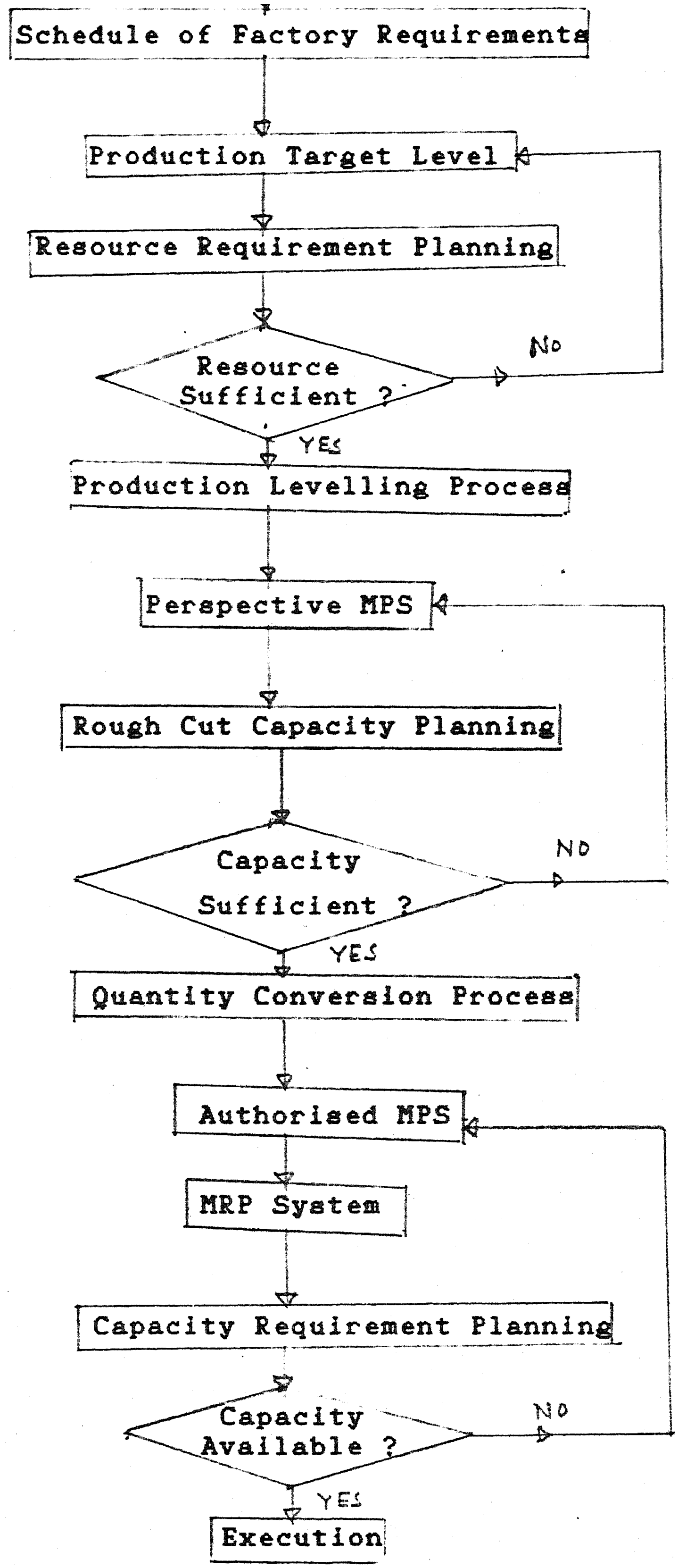


Fig 3.1
Flow Diagram For The Development Of Capacity Constrained MPS

planning system.

At the rough cut capacity planning, the perspective MPS is tested at critical work centres. As such rough cut capacity planning system constitutes the resource testing at critical work centres and adjusting the production to make it feasible on these work centres. The output of this process is the period wise production schedule of each product.

The period wise production schedule is converted to time bucket wise production schedule based on factory calender. The time bucket wise schedule is termed as authorised MPS . It is fed into the MRP system.

Authorised MPS is inputted into MRP system to generate time phased requirements of manufactured components and purchased materials and to schedule planned orders by using the selected lot sizing technique. Any of the nine lot sizing policies described later in section 3.8.3.6 can be selected for this purpose.

The time phased requirement of components generated by MRP system and their resource profiles are fed into capacity requirement planning system to calculate the capacity requirement at each work centre in each time bucket. If capacity at any work centre in any time bucket is exceeded then it can be adjusted by changing MPS or lot sizing policy applied to schedule the planned orders. It can also be taken care by providing over time at the work centres.

In the following sections, the methodology for the development of capacity constrained MPS is discribed in detail. It is discussed under four major modules of the hierarchial decision

making process, viz;

1. Resource Requirement Planning
2. Rough Cut Capacity Planning
3. Material Requirement Planning
4. Capacity Requirement Planning.

3.4 Notations :

The following variables and parameters will be used in the models development described in the later sections:

A_{jk} Amount of product j scheduled for production in time period k

O_{ij} Standard operation time in minute required on work centre i per product j

T_j Effective target production level for product j

D_{jk} Demand forecast for product j in time period k

E_i Efficiency of work centre i (standard vs actual)
actual/available productive hours

P_i Available man/machines in work centre i

F_i Estimated failure allowance on work centre i

S_{ij} Set-up time in minute required on work centre i for product j

M Total number of work centres

N Total number of products

K Total number of time periods

3.5 Resource Requirement Planning :

In Resource Requirement Planning the available capacity is compared with the capacity required to fullfil the demand requirements. The proposed methodology does not optimize the

utilisation of resources but only helps in obtaining the realistic data for use in Rough Cut Capacity Planning. The various steps involved in the resource requirement planning module are described below:

3.5.1 Production Target Setting :

The desired target production for each product is calculated as the average requirement of the product over the planning horizon. For these production targets the number of man / machine required at each work centre is calculated. For each work centre (W.C.) resource planner can compare the resources and reschedule them. With the rescheduled resource level the effective production targets are recalculated.

3.5.2 Resource Requirement Calculation:

Additional Notations :

G_j Desired production target level of product j

H Average number of working days in a planning horizon period

W_i Working time available per day for work centre i in minutes

V_{ij} Total variable time in minute required on work centre i by product j

U_{ij} Total time in minute required on work centre i by product j

N'_i Number of man/machine required in work centre i

The estimated total variable time required at work centre i by product j is :

$$V_{ij} = \frac{O_{ij} \quad G_j}{E_i} \qquad \ldots\ldots \qquad (1)$$

The total time required by product j on work centre i is obtained by adding set-up time to equation (1).

$$U_{ij} = V_{ij} + S_{ij} \qquad \ldots\ldots \qquad (2)$$

The total variable work load on work centre i, $V_{i.}$, is given by

$$V_{i.} = \sum_{j=1}^{N} V_{ij} \qquad \ldots\ldots \qquad (3)$$

Similarly, the total work load on work centre i is obtained from

$$U_{i.} = \sum_{j=1}^{N} U_{ij} \qquad \ldots\ldots \qquad (4)$$

The number of man/machine required at work centre i,

$$N'_i = \frac{U_{i.}}{H \quad W_i}$$

3.5.3 Calculating Production Target:

With the given resources the production level adjustment factor for work centre is calculated as :

Where, C is estimated shop load factor. It is an estimate of the maximum utilisation that could be expected for any work centre under normal operating conditions.

The effective capacity adjustment factor for the shop is then computed as follows:

$$Z^* = \min(Z_i)$$

If the resulting value is greater than 1.0 than the given capacity is more than the required capacity for desired production targets. However, if it is less than 1.0 the desired production targets can not be met. The effective production target is found by multiplying the production level by Z^* for all those products which are processed on work centre for which $Z_i = Z^*$. Again, Z^* and corresponding work centre is identified. This process is repeated till $Z^* \geq 1$. The final set of values for effective production targets are denoted by T_j, j= 1,2,..N.

3.6 Production Levelling

The aim of production levelling is to level the production of each product over the planning horizon to remove the peaks and spikes in the production. The benefit of levelled production is that it generates uniform capacity requirement on the shop floor. An algorithm has been developed for this purpose.

The basic inputs for generating levelled production are the requirements in each period, effective production targets,

begining on hand inventory and safety stock for each product. The output of the process is a smoothed and levelled production schedule for each product.

Additional Notations :

I_{jk} Ending inventory without backlog - safety stock, in period k for product j

Q_j Safety stock for product j

B_j On hand inventory at the beginning of planning horizon for the product j

The various steps of algorithm are as follows.
Consider any product j.
steps:

1. Set $A_{jk} = T_j$ for k = 1 to K.

2. Calculate $I_{j,1} = (A_{j1} - D_{j1}) + (B_j - Q_j)$

3. Calculate $I_{jk} = I_{j,k-1} + A_{jk} - D_{jk}$ if $I_{j,k-1} > 0$

   $I_{jk} = A_{jk} - D_{jk}$ if $I_{J,k-1} <= 0$

   for k = 2 to K.

4. Scan I_{jk} from last period K to period X such that :

   $I_{jk} > 0$ for k = X to K

   and $I_{j,x-1} \leq 0$

5 Set $A_{jx} = T_j - \min(I_{jk})$ k = X to K

6.Repeat steps 2-5 until X = K.

7.Set $A_{jk} = A_{jk} - I_{jk}$ for $I_{jk} < 0$

$= A_{jk}$ for $I_{jk} >= 0$.

The methodology further assumes that all parts for an end product can be produced and the product assembled in a single time period. Since the methodology is developed as strategic planning tool the smallest time period would probably be one month.

Finally methodology does not directly consider the effect of material handling, queueing delays, or material availability. The effect of material handling, queueing and material availability is assumed to be contained in the manufacturing lead times and the user's estimate of shop load factor of the system under analysis. The shop load factor is an estimate of the maximum utilization that could be expected for any work centre under normal operating conditions.

The methodology is presented in three stage. The first stage is the formulation of the general model which allows the computation of the estimated fraction of time required on each work centre for a stated production plan. The second stage presents a procedure which allows the elimination of non-key or non-constraining machine from further analysis. The third stage provides a procedure for adjusting the production level based on the identified critical machines.

Additional Notations :

H_{ik} Available production time in minute on work centre i in time period k

V_{ijk} Estimated total variable time in minute required on work centre i by product j in time period k

U_{ijk} Estimated total time in minute required on work centre i by product j in time period k

R_{ijk} Estimated capacity fraction required on work centre i by product j in time period k

3.7.2 Formulation of Problem

The estimated total variable time required on work centre i by product j in time period k is computed as follows:

$$V_{ijk} = \frac{O_{ij} A_{jk} F_i}{E_i} \qquad \text{.....(6)}$$

Adjusting this estimated variable time to include setup yields the estimated total machine time utilized on work centre i by product j in time period k :

$$U_{ijk} = V_{ijk} + S_{ij} X_{jk} \qquad \text{......(7)}$$

where,

$$X_{jk} = \begin{cases} 1 \text{ if product j is produced in time period k} \\ 0 \text{ otherwise} \end{cases}$$

The resulting U_{ijk} value provides an estimate of the total time required which includes the standard operation time adjusted by the efficiency, the setup time and an estimate of the failure time. The estimated required capacity fraction by product can then be computed as follows:

$$R_{ijk} = U_{ijk} / H_{ik} \qquad \text{.... (8)}$$

Similarily the equivalent values for all products can be calculated as:

$$V_{i.k} = \sum_{j=1}^{N} V_{ijk} = \sum_{J=1}^{N} \frac{O_{ij}\ A_{jk}\ F_i}{E_i} \qquad \ldots\ldots(9)$$

$$U_{i.k} = \sum_{j=1}^{N} U_{ijk} = V_{i.k} + \sum_{j=1}^{N} S_{ij}\ X_{jk} \qquad \ldots\ldots\ (10)$$

$$R_{i.k} = U_{i.k}\ /\ H_{ik} = \sum_{j=1}^{N} R_{ijk} \qquad \ldots\ldots\ (11)$$

where, $R_{i.k}$ represents the estimated fraction of time required on work centre i in time period k for the stated production plan.

3.7.3 Identification Of Critical Work Centres:

The following procedure was developed to identify the set of critical machines which may create capacity problem. Since the product mix may vary over the time frame under consideration, it is necessary to consider all possible combinations of product mix. The worst case would be to examine all time periods to determine the maximum amount of each product to be produced and calculate the required capacity fraction for this worst case product mix.

Let $R_{i..}$ be the capacity fraction for work centre i for the worst case product mix and minimum available time in a period over the planning horizon.

$$R_{i..} = \left[\sum_{j=1}^{N} \frac{O_{ij}\, A_{j.}\, F_i}{E_i} + S_{ij} X_{j.} \right] \Big/ H_{i.}$$

.....(12)

where,

$A_{j.} = \text{Max}\,(A_{j1}, A_{j2}, A_{j3}, \ldots\ldots\ldots, A_{jk})$

$H_{i.} = \text{Min}\,(H_{i1}, H_{i2}, H_{i3}, \ldots\ldots\ldots, H_{ik})$

$$X_{j.} = \begin{cases} 1 & \text{if } A_{j.} \text{ is positive} \\ 0 & \text{otherwise.} \end{cases}$$

The machines which have values of $R_{i..}$ less than the selected shop load factor are eliminated from further consideration. The choice of the shop load factor dependents on the anticipated congestion within the system being analyzed and may range from 0.65 to 0.95. The lower values represent systems with irregular flows and many potential conflicts while the higher values represent systems with smooth flows and high potential machine utilization values. As long as the product mix does not vary beyond the maximum values of production volumes used in the previous computations, it is not necessary to repeat this stage.

3.6.4 Computing the Production Adjustment:

The previous procedure allows the user to identify the critical machines and to compute whether or not a system has the available capacity to produce a given production level. In order to compute the effective capacity it is necessary to estimate the shop load factor which defines maximum or effective capacity and increase, or decrease, the production level to achieve that

value. Since the degree of adjustment is only dependent on the variable components, all of the critical machines must be considered. The potential adjustment per machine is computed as follows:

$$Z_{ik} = \frac{CH_{ik} - \sum_{j=1}^{N} S_{ij} X_{jk}}{V_{i.k}} \qquad \ldots\ldots(13)$$

where, Z_{ik} = production level adjustment factor for work centre i in time period k and C = estimated shop load factor.

The effective capacity adjustment factor $Z_{.k}$ for the entire system in time period k can then be computed as follows:

$$Z_{.k} = \min(Z_{1k}, Z_{2k}, Z_{3k}, \ldots\ldots\ldots, Z_{Mk}).$$

If the resulting value is greater than 1.0, the effective production capacity is greater than the requested production. If the value is less than 1.0, the requested production can not be met. Thus the resulting percent of increase, or decrease, in the production level in time period k is :

$$(1-Z_{.k})100$$

The effective capacity for time period k is found by multiplying the resulting $Z_{.k}$ value by A_{jk}, the amount of product j scheduled for production in time period k, for those products which are processed on the work centre for which $Z_{ik} = Z_{.k}$. This method reduces the production of all such products by same proportion.

Alternatively, the production of the selected products can be reduced keeping the production of other products constant. A priority rule has been developed to select the product for reducing the overall production. The product for which the factor given below is highest is selected for reducing the production.

$(A_{jk} - T_j) / D_{jk}$ for period k under consideration.

Let the product selected by the above criterion be identified as 'l'. All such work centres on which product 'l' is processed are identified as S. For each 'i' work centre contained in S production adjustment factor is calculated using the following relationship.

$$Y_{ilk} = \frac{V_{ilk} + C.H_{ik} - U_{i.k}}{V_{ilk}} \quad .. \quad (14)$$

Effective capacity adjustment factor is:

$$Y_{.lk} = \min(Y_{ilk}); \qquad i \in S$$

The modified production schedule for product 'l' is $\max(Y_{.lk} \cdot A_{lk}, T_j)$. The process of selecting the product and reducing the production is repeated till $Y_{.lk}$ becomes equal to or greater than 1.0 or the production of all products has been reduced to effective production target level. If the production of all the products has been reduced to target production level and value of $Y_{.lk}$ is still less than 1.0 then the production level is

further reduced by decreasing the production of the products by same proportion. As discussed in the first option for product adjustment.

The modified master production schedule obtained after rough cut capacity planning is inputted into MRP system.

3.8 MRP System

3.8.1 Prerequisites and Assumptions :

The following are the prerequisites and the assumptions of the MRP system developed.

1. Each inventory item must be unambiguously identified through a unique code (part number).
2. Availability of inventory records for all items under the system's control.
3. For system's effective operation, file data integrity pertaining to inventory status data and the product structure is needed because MRP can even process faulty data.
4. Lead times for all inventory items are known and can be supplied to the system.
5. All the components of an assembly are needed at the time of assembly order release.
6. Disbursement and usage of materials is assumed to be discrete.
7. Process dependencies (eg. set-up dependencies) are not considered.

The main inputs to an MRP system are : MPS, product structure of each end item and inventory status data.

3.8.2.1 Master Production Schedule

MPS fed into MRP system is obtained after resource requirement planning and production levelling. This MPS gives planning period wise production schedule. But MRP system requires time bucket wise production schedule of the items. This is done by quantity conversion process which is discussed in detail in later section of the chapter.

Independent demand for components which includes service part requirements, inter plant requirement etc. is also inputted into the MRP system.

3.8.2.2 Product Structure

It gives the information regarding the relationship between components and assemblies i.e. which component/sub-assembly goes where information. The format used here for the representation of product structure is called the single-level implosion format. This format is that of a where-used list. The product structure is stored as a table showing the list of all the parents (on the immediate higher level only) for each item.

3.8.2.3 Inventory Status File :

This contains individual item inventory records containing the status data required for the determination of the requirements, such as part code, lead time, cost data, on hand

1. The order quantity.

2. The timing of the required order completion (due date).

3. The timing of order release.

The first two tasks are accomplished by lot sizing and the third one by time phasing.

3.8.3.6 Lot sizing:

In material requirements planning, whenever there is a net requirement for a material, a decision must be made concerning how much of the material to order. These decisions are commonly called lot sizing decisions. In produce-to-stock firms, the size of production lots is primarily a question of economics.

As discussed in the literature review, all lot sizing techniques are imperfect and their performance depends on the set of input parameters. For this reason a number of lot sizing techniques which are used in practice are incorporated.

Lot for Lot (LFL) :

This provides period-by-period coverage of net requirements, and the planned order quantity always equals the net requirement of the corresponding period. The use of this technique minimizes inventory carrying cost. It is often used for expensive purchased items, and for any items, purchased or manufactured, that have highly discontinuous demand. That is, items in high volume production and items that pass through specialized facilities geared to continuous production (equivalent to permanent setup) are normally ordered lot for lot.

Fixed Order Quantity (FOQ) :

The order size equals an integer multiple of a specified quantity. This is used where the item has to be purchased/manufactured in certain fixed quantity only. This policy would be applicable to items with ordering cost sufficiently high to rule out ordering in net requirement quantities, period by period.

Minimum Order Quantity (MOQ) :

In this approach, whenever an order is launched, it has to be greater than or equal to a specified minimum quantity.

EOQ :

The concept of EOQ can be incorporated into the MRP system. The value of EOQ is to be computed first and then the orders are to be planned with EOQ as the minimum quantity to be ordered. The EOQ is based on an assumption of continuous, steady-rate demand, and it will perform well only where the actual demand approximates this assumption. But the demand in MRP is both discontinuous and non-uniform. The more discontinuous and non-uniform the demand, the less effective the EOQ will prove to be.

Modified EOQ :

The EOQ is computed and rounded to an integer value. Net requirements are accumulated until it exceeds EOQ. Let period 'n' be the period in which this occures first. Let the ordering point, the period in which we are trying to determine the order quantity be denoted by 'm'. Compute :

$$Q_1 = \sum_{i=m}^{n} d_i \; ; \qquad Q_1 \text{ exceeds EOQ}$$

$$Q_2 = \sum_{i=m}^{n-1} d_i \; ; \qquad Q_2 \text{ is less than EOQ}$$

where, d_i denotes the net requirement in the period i. The order quantity is either Q_1 or Q_2, which ever is closer to EOQ. If EOQ is exactly half-way between Q_1 and Q_2 then the order quantity is chosen to be Q_2.

Fixed Period Requirements (FPR) :

In this approach, the total of net requirements of a specified fixed number of periods is to be ordered at every ordering point. In fixed order quantity approach, the ordering quantity is constant and the ordering intervals vary, while in fixed period requirements approach, the ordering interval is constant (except when there is a zero requirement in a given period, which will extend the ordering interval) and the quantities are allowed to vary.

Period Order Quantity (POQ) :

This approach is based on the logic of EOQ, modified for use in an environment of discrete period demand. EOQ is first computed to determine the number of orders per year that should be placed. Then the number of planning periods is divided by this quantity to determine ordering interval. The POQ technique is identical to FPR except that the ordering

interval is computed. Since this is a fixed interval technique, it avoids 'remnants' in an effort to reduce the inventory carrying cost. For this reason, POQ is more effective than the EOQ, as setup cost per year is the same but carrying cost will tend to be lower under POQ.

Least Unit Cost (LUC) :

In this approach, in determining the order quantity, the LUC technique asks whether this quantity should equal the first period's net requirement or whether it should be increased to cover the next period's requirement also, or the one after that also etc. The decision is based on the unit cost (i.e. set-up and inventory carrying cost per unit) computed for each of the successive order quantities. The one with the least unit cost is chosen to be the order quantity.

Least Total Cost (LTC) :

This approach is based on the rationale that the sum of set-up and inventory costs are as nearly equal as possible. This is achieved through the computation of the so called economic part-period factor or EPP. The EPP is defined as the quantity of the inventory item which if carried in inventory for one period would result in a carrying cost equal to the set-up cost. It is computed by the formula given below.

$$EPP = S / I$$

where S = set-up cost

I = inventory carrying cost/unit/period

The LTC technique selects the order quantity at which the part-period cost most nearly equals the EPP.

Modified LTC:

In this approach, the EPP and part-periods are computed as usual. The order point (m) and the order quantity are determined using the above mentioned LTC procedure. Let the net requirement in the period 'm' be 'd'. The modification is that, if the condition

$$d > EPP$$

is satisfied then an order is placed in period 'm' for that period only (i.e. the order quantity equals d).

Using the lot sizing for lower level components, some MRP users believe that excessive inventory build ups in lower level components can result. Some MRP users argue, however, that excessive inventory levels are not reached. The per unit cost of lower level components leads to higher lot sizes and consequently higher inventory levels. These MRP users content that higher inventory levels of lower level components should not be surprising or disturbing; the economic lot sizing of all levels of components is therefore recommended.

The tendency, in practice, is to use Lot-for-Lot (LFL) at all levels for produce-to-order firms. Also, LFL is used in produce-to-stock firms for end items and assemblies and minimum order quantity lot sizes are used for lower level components. The use of LFL in end items and assemblies avoids the inventory build-ups in lower level components described above.

3.8.3.7 Time Phasing :

The planned order releases are computed from the planned order coverage by offsetting for the lead time i.e. by subtracting the value of the lead time from the order completion time. This process is called time phasing.

3.7.3.8 Explosion of Requirements :

The explosion of the requirements from the MPS down into the various component material levels, is guided by the inventory records. Gross requirements for higher-level items are processed against inventory to determine net-requirements, which are then covered by planned orders using lot-sizing. The planned order releases are determined by time-phasing process. The quantity and timing of planned order releases determine, in turn, the quantity and timing of component gross requirements. This procedure is repetitively carried out for the items on successively lower levels until a purchased item is reached. The requirements planning process stops when all the explosion paths that follow the branches of the product structure have reached purchased items.

There will be recurrence of requirements for a given item if it has more than one parent. Hence, an item record has to be processed only after all its parent records are processed. This is achieved by using the so called low-level coding. The actual coding system is discussed in next chapter.

3.9 Capacity Requirement Planning (CRP) :

The purpose of capacity planning is to check the feasibility of the MPS and generate the time phased requirement

of capacity in various work centres to execute the MRP plan.

3.9.1 Input To CRP :

1. Full parts MRP explosion, material plan and planned order schedule for items/components.
2. Resource profile for each item/component.

Resource Profile :

Resource profile or part route data contains the standard and setup times for an item / component in each of its lead time period on all the work centres where it is to be processed.

Table 1. Resource Profile (An Illustration)

Item/component code :xxx

Lead Time : 2

Time in minute.

W.C. Code	Lead time Period 1		Lead time Period 2	
	Std. time	Setup time	Std. time	Setup time
1001	2.2	40	5.0	30
1002	1.2	10	1.1	50
1009	2.3	4	23.3	120

3.9.2 Output Of CRP :

The output of CRP module is the load profile (Time phased capacity requirement) for each work centre.

In the present system the facility of graphical representation (Histogram) of capacity required vs capacity

available for each work centre has been provided. It helps in quick assesment of the capacity plan.

3.10 Evaluation Of Alternate MPS :

The capacity plan and material plan generated depend on the MPS, lot sizing technique applied to schedule the planned order, lead time and route sheet of item/components. The factors that can be varied in the present system to generate the alternate capacity and material plan are MPS and lot sizing technique applied to schedule planned orders.

For a given set of inputs following values of performance criteria are calculated :

Number of over load work centre

Number of over load work centre periods (sum of the total number of periods on all work centres where over loading occur.s).

Maximum overall over load

Histogram of capacity available vs capacity required for each work centre also helps in evaluating capacity plan.

If the plan is infeasible due to inadequate capacity available in the shop then the shop load factor supplied at rough cut capacity planning stage is changed to get an alternate MPS. If the capacity plan is highly fluctuating and erratic then various lot sizing technique are tried for scheduling the planned orders.

The details of implementation of the proposed capacity constrainted MPS methodology are discussed in chapter IV.

contain too many number of fields in a record because the file is opened and closed many times during the operation and if the file size is large it will take more time in loading, writing and closing the file. On the other hand, the number of files should not be too large, because then too many files will be opened and closed frequently. The data base has been designed keeping these points in view.

4.4 Coding System for Item Code:

The code (part number) of an item is a field with four characters. The first character indicates the level at which the particular item is present in the product structure. The item/s in top most level start with letter A, while the item/s in the second level start with letter B and so on. The second and third characters in the code identify that item among other items present at the same level. The fourth character indicates whether the item is an end item, sub assembly or purchased material. The fourth charcter should be E for an end item, S for a sub-assembly, P for a purchase item.

When the same item exists at several levels in the product structure i.e., the item has multiple parents at different level, there will be recurrence of gross requirement. This problem is solved by employing the so called low level coding technique. The first character should correspond to the lowest level at which the inventory item appears in the product structure. After the inputs are taken from the user, the records of MRP data file are sorted on the item code. Then the sequential processing on this sorted

file will ensure the level by level process to run correctly.

4.5 Data Files:

The system stores data in six data files. These are file of records. The data files used are Dmd.dat, Critical.dat, shop.dat, Operation.dat, Mrpdata.dat and Misc.dat. These data files are explained below.

1. Dmd.dat: Key field: Product code. This contains data about demand forecast and prodution schedule for each product in each period of planning horizon.

2. critical.dat: Key field: Work Centre code. It contains data of those machines which are likely to cause bottleneck problems on the shop floor. All the fields of the record are calculated by the system itself while running rough cut capacity planning module.

3. Shop.dat: Key field: Work centre code. This contains details of each work centre, its capacity and performance parameters like efficiency , failure allowance etc.

4. Operation.dat:Key fields: Machine code, product code. It contains aggregate data about time consumed (standard and setup time) by each product on various work centres where it is processed. They are used by resource requirement planning and rough cut capacity planning module. All the desired data is obtained from product structure file and resource profile for each item/ component.

5. Mrpdata.dat: Foreign Key: Product code, Key Field :Item Code
It contains data about product structure and the resource profile of the each item/ component. Unique identifier for each record is item code. The records are sorted on item code. It also contains details of inventory status of each item/ component.

6. Misc.dat: It contains only one record which has the details about factory calender, current number of planning period and time buckets and number of planning periods etc.

4.6 Implementation Features:

The system implemented is menu driven. The opening menu (main menu) has three options:

Database creation

Editing database

and CCMPS development.

4.6.1 Database Creation:

Four basic data files created by the user are:

Production Schedule data file (Dmd.dat)

Work centre data file (Shop.dat)

Product Structure, Item status and resource profile data file (mrpdata.dat).

Calender for the factory (Misc.dat)

Every attempts has been made to make data entries fool proof., However, user has to be careful about the validity and integrity of data among the files, i.e., data in various files should relate to only one integrated manufacturing system.

4.6.2 Edit Database:

It helps in updating and browsing the database files. Here the following facilities are provided.

1. Browse data base
2. Change a record
3. Delete a record
4. Add a record.

4.6.3 MPS Development:

It has sub-modules as :

Resource Requirement Planning

Rough Cut Capacity Planning

M R P process

Capacity Requirement Planning

Performance Report.

Resource Requirement Planning:

This module is interactive. It first assumes production target level as the average product demand over the planning horizon. Here, the user has to supply shop load factor and interact through following four options:

1. List overload work centres
2. List underload work centres
3. Change the capacity of a work centre
4. Recalculate the effective production targets

The capacity of each work centre planned at this process is considered inflexible in further preperation of MPS.

Rough Cut Capacity Planning:

It calculates the feasible production schedule for each period for user supplied shop load factor. If the capacity is inadequate in a period to support the developed production schedule the user has two options for changing product mix and production level.

1. Change the production of each product by the same proportion.
2. Change the production by the priority rule implemented in the system.

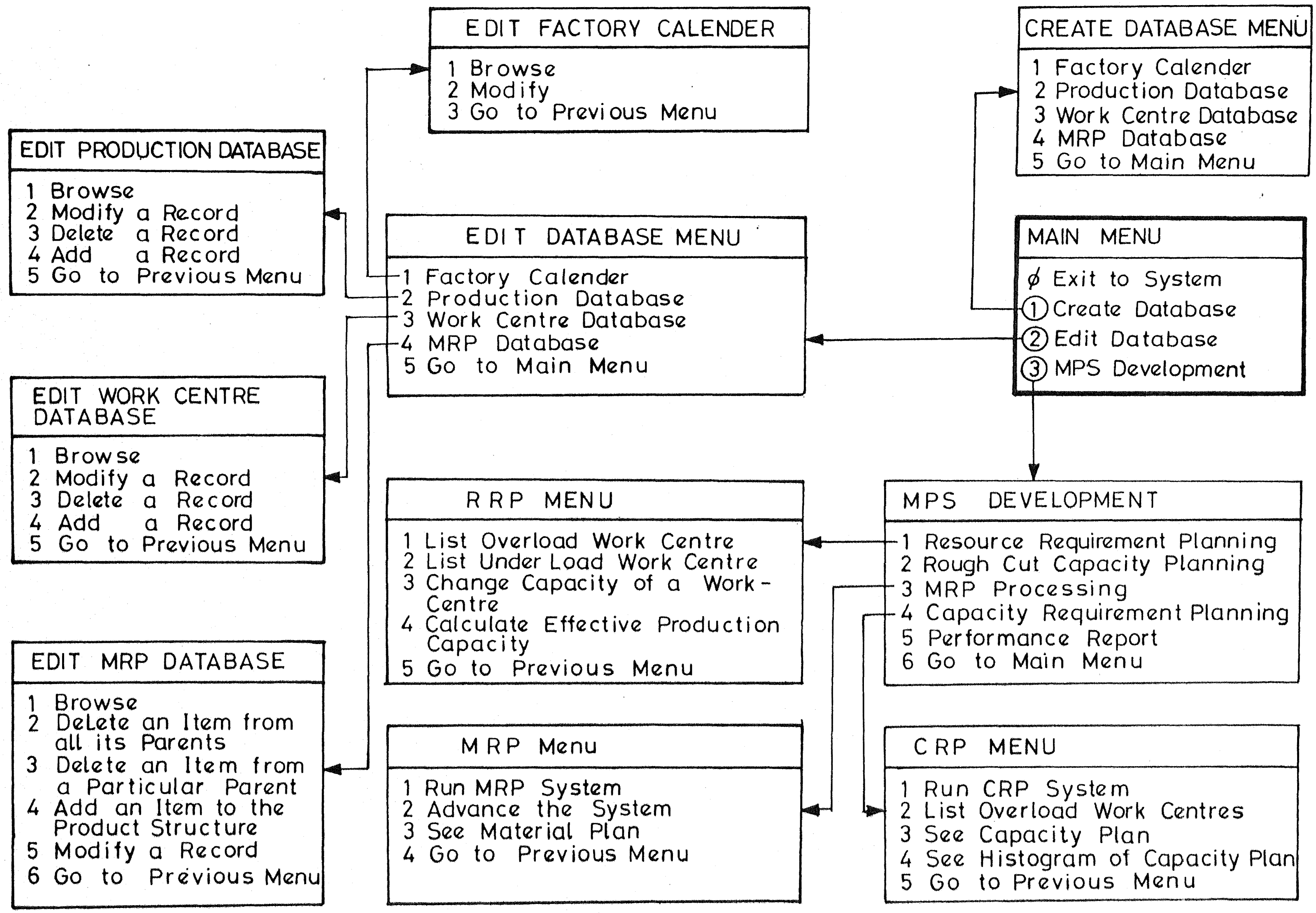
MPS Processing :

It explodes product structure and generates time phased material requirement for each item/component. It provides the option for applying a particular lot sizing technique to schedule the planned orders. All the nine lot sizing techniques discussed in section 3.8.3.6 have been implemented. Facility has been provided for advancing the MRP system by one time bucket.

Capacity Requirement Planning:

This module generates time phased capacity requirements for each work centre using the planned orders scheduled by MRP processor and resource profile for each item/ component. It provides the following two options to the users.

1. List overload work centres
2. View histogram of capacity available Vs. Capacity required for a work centre.


MAIN MENU
ø Exit to System
1 Create Database
2 Edit Database
3 MPS Development
CREATE DATABASE MENU
1 Factory Calender
2 Production Database
3 Work Centre Database
4 MRP Database
5 Go to Main Menu
EDIT DATABASE MENU
1 Factory Calender
2 Production Database
3 Work Centre Database
4 MRP Database
5 Go to Main Menu
EDIT FACTORY CALENDER
1 Browse
2 Modify
3 Go to Previous Menu
EDIT PRODUCTION DATABASE
1 Browse
2 Modify a Record
3 Delete a Record
4 Add a Record
5 Go to Previous Menu
EDIT WORK CENTRE DATABASE
1 Browse
2 Modify a Record
3 Delete a Record
4 Add a Record
5 Go to Previous Menu
EDIT MRP DATABASE
1 Browse
2 Delete an Item from all its Parents
3 Delete an Item from a Particular Parent
4 Add an Item to the Product Structure
5 Modify a Record
6 Go to Previous Menu
MPS DEVELOPMENT
1 Resource Requirement Planning
2 Rough Cut Capacity Planning
3 MRP Processing
4 Capacity Requirement Planning
5 Performance Report
6 Go to Main Menu
RRP MENU
1 List Overload Work Centre
2 List Under Load Work Centre
3 Change Capacity of a Work-Centre
4 Calculate Effective Production Capacity
5 Go to Previous Menu
MRP Menu
1 Run MRP System
2 Advance the System
3 See Material Plan
4 Go to Previous Menu
CRP MENU
1 Run CRP System
2 List Overload Work Centres
3 See Capacity Plan
4 See Histogram of Capacity Plan
5 Go to Previous Menu

Performance Report: The following performance reports are generated for the capacity plan.

* Number of overload work centres.
* Number of overload work centre periods
* Maximum overall overload

4.7 Limitations of the System:

1. The data item specified as integer can not exceed the value 32767. This limitation is imposed by the programming language used (Turbo Pascal Version 3.01).
2. Replanning of the MRP system is restricted to advancing the time frame by one bucket bucket at a time.
3. The proposed system can support a maximum of 26 Bill of Material Levels and a maximum of 17576 items.

4.8 TESTING:

A number of problems of varied product structure were tested on the CCMPS system. All the data were generated hypothetically. Results of a typical test problem are given in appendix I.

CHAPTER V

CONCLUSIONS

Using Turbo Pascal Version 3.01, a system for " Capacity Constrained Master Production Schedule for MRP system" has been developed.

The proposed system in its present form can support a maximum of 26 levels in the product structure. Further the maximum number of items can not exceed 17576. A modular approach has been adopted for the development of the four basic decision making modules, viz., Resource Requirement Planning, Rough Cut Capacity Planning, Material Requirement Planning and Capacity Requirement Planning. The user can vary the shop load factor and choice of lot sizing technique for individual item/component to study their implications on the loading of the various work centres. The system has the capacity to graphically display period wise capacity required vs capacity available on each work centre. Every effort has been made to make the developed system user friendly.

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APPENDIX I

The results of a sample problem run on the system are shown below.

INPUT DATA :

Length of a period = 1 month

Length of a time bucket = 1 week

Number of products = 3

Number of work centres = 6

Number of periods in planning horizon = 8

Number of time buckets for MRP explosion = 11

Demand Forecast Data:

	Product		
Period	X01	X02	X03
1	1400	1652	1500
2	1652	1324	1623
3	1873	1342	1432
4	1600	1763	1866
5	1500	1234	1543
6	1452	1985	1752
7	1265	1543	1542
8	1642	1865	1965

Product	Quantity on hand	Safety stock
X01	500	300
X02	600	400
X03	300	100

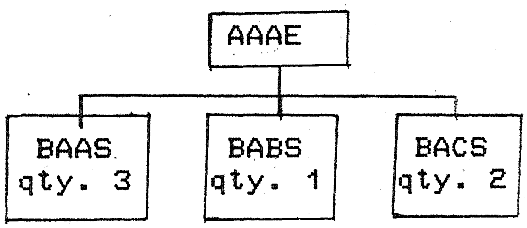
Work Centre Database :

W.C.Code	Efficiency	No. of Man/Machine	Working Hour/Day	Failure Allowance
M1	0.98	14	8.0	1.1
M2	0.98	10	7.0	1.05
M3	0.98	11	8.0	1.1
M4	0.9	11	7.0	1.07
M5	0.95	14	8.0	1.02
M6	0.95	11	7.0	1.03

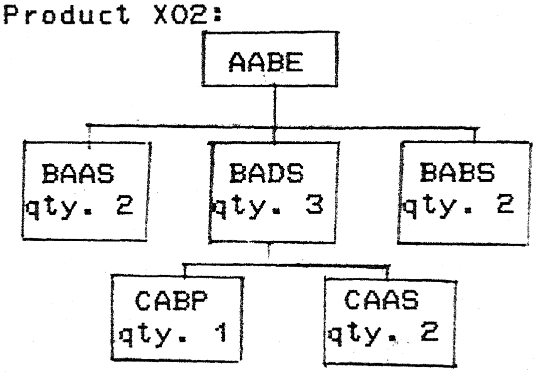
Product structure Diagram:

qty. denotes the number of an item that are required to make one unit of its parent item.

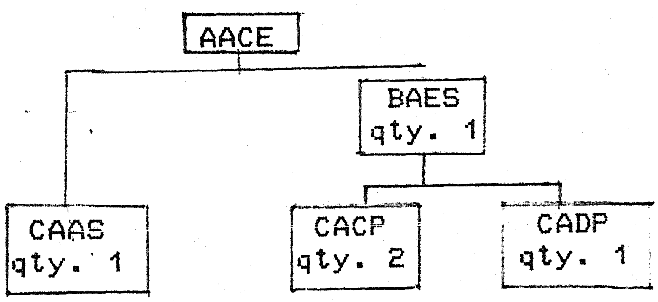
End Product X01:



End Product X02:



End Product X03:



Product Structure And Resource Profile Data:

1.

Item Code : AAAE
Product Code : X01
Set up cost (Rs) : 400.0
Inventory carry cost/unit/week (Rs) : 1.0
Lead Time (LT) : 1 week

Resource Profile :

All times in minutes.

LT period 1.

W.C. Code	Std. Time	set up Time
M1	5.0	10.0
M3	8.0	29.0
M4	14.0	30.0

2.

Item Code : AABE
Product Code : X02
Set up cost (Rs) : 450.0
Inventory carry cost/unit/week (Rs) : 2.0
Lead Time (LT) : 2 week

All times in minutes.

Resource Profile :

	LT period 1.		LT period 2	
W.C. Code	Std. Time	Set up Time	Std. Time	Set up Time
M3	2.0	23.0	1.0	11.0
M1	5.0	12.0	5.0	12.0

3.

Item Code : AACE
Product Code : X03
Set up cost (Rs) : 650.0
Inventory carry cost/unit/week (Rs) : 3.0
Lead Time (LT) : 1 week

Resource Profile : All times in minutes.

LT period 1.

W.C. Code	Std. Time	Set up Time
M2	3.0	11.0
M1	5.0	14.0

4.

Item Code : BAAS
Parent 1/Quantity : AAAE /3
Parent 2/Quantity : AABE /2

Set up cost (Rs) : 450.0

Inventory carry cost/unit/week (Rs) : 5.0
Lead Time (LT) : 1 week

Resource Profile : All times in minutes.

LT period 1.

W.C. Code	Std. Time	Set up Time
M1	10.0	37.0
M3	17.0	28.0

5.

Item Code : BABS
Parent 1 /Quantity: AAAE / 1
Parent 2 /Quantity: AABE / 2

Set up cost (Rs) : 700.0

Inventory carry cost/unit/week (Rs) : 5.0
Lead Time (LT) : 2 week

Resource Profile :

	LT period 1.		LT period 2	
W.C. Code	Std. Time	Setup Time	Std. Time	Setup Time
M4	5.0	20.0	0	0
M5	15.0	25.0	0	0
M1	0	0	14	29

6.

Item Code : BACS
Parent / Quantity : AAAE / 2
Set up cost (Rs) : 50.0
Inventory carry cost (Rs) : 1.0
Lead Time (LT) : 1 week

Resource Profile :

All times in minutes.

LT period 1.

W.C. Code	Std. Time	Set up Time
M2	10.0	25.0
M6	8.0	28.0

7.

Item Code :BADS
Parent / Quantity :AABE / 3
Set up cost (Rs) : 100.0
Inventory carry cost/unit/week (Rs) : 5.0
Lead Time (LT) : 1 week

Resource Profile :

LT period 1. Alltimes in minutes.

W.C. Code	Std. Time	Set up Time
M5	11.0	21.0
M6	7.0	28.0

8.

Item Code :BAES
Parent / Quantity :AACE / 1
Set up cost (Rs) : 500.0
Inventory carry cost/unit/week (Rs) : 1.50
Lead Time (LT) : 1 week

Resource Profile :

LT period 1. Alltimes in minutes.

W.C. Code	Std. Time	Set up Time
M5	10.0	15.0
M6	9.0	11.0

9.

Item Code : CAAS
Parent 1 / Quantity : BADS / 2
Parent 2 / Quantity : AACE / 1

Set up cost (Rs) : 150.0

Inventory carry cost/unit/week (Rs) : 4.0
Lead Time (LT) : 1 week

All times in minutes.

Resource Profile :

LT period 1.

W.C. Code	Std. Time	Set up Time
M5	10.0	20.0
M4	5.0	28.0
M6	9.0	34.0

10

Item Code :CABP
Parent / Quantity :BADS / 1
Order cost (Rs) : 500.0
Inventory carry cost/unit/week (Rs) : 2.0
Lead Time (LT) : 2 week

11

Item Code :CACP
Parent / Quantity :BAES / 2
Order cost (Rs) : 1000.0
Inventory carry cost/unit/week (Rs) : 2.0
Lead Time (LT) : 1 week

12

Item Code :CADP
Parent / Quantity :BAES / 1
Order cost (Rs) : 50.0
Inventory carry cost/unit/week (Rs) : 0.25
Lead Time (LT) : 1 week

Rough Cut Capacity Planning :

Shop load Limit : 0.78

Critical Work Centres:

Work Centre Code	Capacity Utilisation Factor
M1	1.05
M3	0.88
M4	0.83
M5	0.87
M6	1.03

Production Adjustment:

Period 1 :

Capacity available in period 1 is 0.96 times of the required capacity for the requested production in the period.

Production schedule for the period 1 is adjusted by Priority Rule.

Period 2:

Capacity available in period 2 is 1.01 times of the required capacity for the requested production in the period.

No adjustment in production schedule needed.

Period 3:

Capacity available in period 3 is 0.88 times of the required capacity for the requested production in the period.

Production schedule for the period 3 is adjusted by Priority Rule.

Period 4:

Capacity available in period 4 is 0.88 times of the required capacity for the requested production in the period.

Production schedule for the period 4 is adjusted by Priority Rule.

Period 5:

Capacity available in period 5 is 0.91 times of the required capacity for the requested production in the period.

Production schedule for the period 5 is adjusted by Priority Rule.

Period 6:

Capacity available in period 6 is 0.87 times of the required capacity for the requested production in the period.

Production schedule for the period 6 is adjusted by Priority Rule.

Period 7:

Capacity available in period 7 is 0.78 times of the required capacity for the requested production in the period.

Production schedule for the period 7 is adjusted by Priority Rule.

Period 8:

Capacity available in period 8 is 0.7 times of the required capacity for the requested production in the period.

Production schedule for the period 8 is adjusted by Priority Rule.

The Production Schedule obtained after Rough Cut Capacity Planning is as follows:

	Product		
Period	X01	X02	X03
1	1416	1452	1510
2	1479	1517	1578
3	1351	1386	1442
4	1548	1468	1527
5	1351	1386	1442
6	1273	1330	1383
7	1134	1205	1253
8	1222	1254	1304

MRP system and CRP system has been run for two sets of data obtained by varying the lot sizing techniques applied to schedule planned orders for an item.

For the first set of data following lot sizing techniques have been applied.

Item Code	Lot Sizing Technique
AAAE	EOQ
AABE	LFL
AACE	LFL
BAAS	FPR (fixed period value = 700)
BABS	LFL
BACS	Modified LTC
BADS	LUC
BAES	Modified LTC
CAAS	FOQ (order quantity = 1000)
CABP	POQ
CACP	LFL
CADP	FOQ (order quantity = 800)

For the second set of data Lot for lot lot sizing technique has been applied to all the items for scheduling planned orders.

The material plan and capacity plan for the two sets of data are shown later.

The vertical height of the bar in the histogram shows capacit in man hour or machine hour. Bar A shows available capacity whereas R denotes required capacity.

RESULTS OF FIRST SET OF DATA FOLLOW

TABLE I

Item code:AAAE
Safety stock: 300

Lead time: 1
Lot size: E O Q

Beginning inventory: 500

Period:	1	2	3	4	5	6	7	8	9	10	11
Gross:	321	321	321	321	320	321	257	257	321	192	257
Sch.Recpts:	0	0	0	0	0	0	0	0	0	0	0
Net:	121	321	321	321	320	321	257	257	321	192	257
Plan Recpts:	121	483	483	0	483	483	0	483	483	0	0
Ending Inv.:	0	162	324	3	166	328	71	297	459	267	10
Ord.Release:	483	483	0	483	483	0	483	483	0	0	0

Total cost of ordering and inventory carrying : 4487.00

Orders to be expedited :
An order of 121 to be released in period -1 for requirement in period

press RETURN to continue.......

TABLE II

Item code:AABE
Safety stock: 400

Lead time: 2
Lot size: Lot for Lot

Beginning inventory: 600

Period:	1	2	3	4	5	6	7	8	9	10	11
Gross:	330	330	330	330	329	329	263	263	329	197	264
Sch.Recpts:	0	0	0	0	0	0	0	0	0	0	0
Net:	130	330	330	330	329	329	263	263	329	197	264
Plan Recpts:	130	330	330	330	329	329	263	263	329	197	264
Ending Inv.:	0	0	0	0	0	0	0	0	0	0	0
Ord.Release:	330	330	329	329	263	263	329	197	264	0	0

Total cost of ordering and inventory carrying : 4050.00

Orders to be expedited :
An order of 130 to be released in period -2 for requirement in period
An order of 330 to be released in period -1 for requirement in period

press RETURN to continue.......

TABLE III

Item code:AACE   Lead time: 1   Beginning inventory: 300
Safety stock: 100   Lot size: Lot for Lot

Period:	1	2	3	4	5	6	7	8	9	10	11
Gross:	343	343	343	343	342	343	274	274	343	205	274
Sch.Recpts:	0	0	0	0	0	0	0	0	0	0	0
Net:	143	343	343	343	342	343	274	274	343	205	274
Plan Recpts:	143	343	343	343	342	343	274	274	343	205	274
Ending Inv.:	0	0	0	0	0	0	0	0	0	0	0
Ord.Release:	343	343	343	342	343	274	274	343	205	274	0

Total cost of ordering and inventory carrying : 6500.00

Orders to be expedited :
An order of 143 to be released in period -1 for requirement in period 1

press RETURN to continue.......

TABLE IV

Item code:BAAS   Lead time: 1   Beginning inventory: 100
Safety stock: 10   Lot size: Fixed Period Requirements

Period:	1	2	3	4	5	6	7	8	9	10	11
Gross:	2109	2109	658	2107	1975	526	2107	1843	528	0	0
Sch.Recpts:	0	0	0	0	0	0	0	0	0	0	0
Net:	2019	2109	658	2107	1975	526	2107	1843	528	0	0
Plan Recpts:	2019	2767	0	4082	0	2633	0	2371	0	0	0
Ending Inv.:	0	658	0	1975	0	2107	0	528	0	0	0
Ord.Release:	2767	0	4082	0	2633	0	2371	0	0	0	0

Total cost of ordering and inventory carrying : 28140.00

Orders to be expedited :
An order of 2019 to be released in period -1 for requirement in period

press RETURN to continue.......

TABLE V

Item code:BABS Lead time: 2 Beginning inventory: 100
Safety stock: 10 Lot size: Lot for Lot

Period:	1	2	3	4	5	6	7	8	9	10	11
Gross:	1473	1473	987	1470	1272	789	1470	1074	792	0	0
Sch.Recpts:	0	0	0	0	0	0	0	0	0	0	0
Net:	1383	1473	987	1470	1272	789	1470	1074	792	0	0
Plan Recpts:	1383	1473	987	1470	1272	789	1470	1074	792	0	0
Ending Inv.:	0	0	0	0	0	0	0	0	0	0	0
Ord.Release:	987	1470	1272	789	1470	1074	792	0	0	0	0

Total cost of ordering and inventory carrying : 8750.00

Orders to be expedited :
An order of 1383 to be released in period -2 for requirement in period 1
An order of 1473 to be released in period -1 for requirement in period 2

press RETURN to continue.......

TABLE VI

Item code:BACS Lead time: 1 Beginning inventory: 100
Safety stock: 7 Lot size: Modified LTC

Period:	1	2	3	4	5	6	7	8	9	10	11
Gross:	966	966	0	966	966	0	966	966	0	0	0
Sch.Recpts:	0	0	0	0	0	0	0	0	0	0	0
Net:	873	966	0	966	966	0	966	966	0	0	0
Plan Recpts:	873	966	0	966	966	0	966	966	0	0	0
Ending Inv.:	0	0	0	0	0	0	0	0	0	0	0
Ord.Release:	966	0	966	966	0	966	966	0	0	0	0

Total cost of ordering and inventory carrying : 250.00

Orders to be expedited :
An order of 873 to be released in period -1 for requirement in period 1

press RETURN to continue.......

TABLE IX

Item code:CAAS Lead time: 1 Beginning inventory: 100
Safety stock: 39 Lot size: Fixed Order Quantity

Period:	1	2	3	4	5	6	7	8	9	10	11
Gross:	1663	1659	1659	1394	1395	1590	1062	1399	205	274	0
Sch.Recpts:	0	0	0	0	0	0	0	0	0	0	0
Net:	1602	1659	1659	1394	1395	1590	1062	1399	205	274	0
Plan Recpts:	1602	2000	2000	1000	2000	1000	1000	2000	0	0	0
Ending Inv.:	0	341	682	288	893	303	241	842	637	363	363
Ord.Release:	2000	2000	1000	2000	1000	1000	2000	0	0	0	0

Total cost of ordering and inventory carrying : 25815.00

Orders to be expedited :
An order of 1602 to be released in period -1 for requirement in period

press RETURN to continue.......

TABLE X

Item code:CABP Lead time: 2 Beginning inventory: 100
Safety stock: 40 Lot size: Period Order Quantity

Period:	1	2	3	4	5	6	7	8	9	10	11
Gross:	660	658	658	526	526	658	394	528	0	0	0
Sch.Recpts:	0	0	0	0	0	0	0	0	0	0	0
Net:	600	658	658	526	526	658	394	528	0	0	0
Plan Recpts:	600	658	658	526	526	658	394	528	0	0	0
Ending Inv.:	0	0	0	0	0	0	0	0	0	0	0
Ord.Release:	658	526	526	658	394	528	0	0	0	0	0

Total cost of ordering and inventory carrying : 3000.00

Orders to be expedited :
An order of 600 to be released in period -2 for requirement in period
An order of 658 to be released in period -1 for requirement in period

press RETURN to continue.......

TABLE XI

Item code:CACP   Lead time: 1   Beginning inventory: 100
Safety stock: 25   Lot size: Lot for Lot

Period:	1	2	3	4	5	6	7	8	9	10	11
Gross:	686	686	684	1234	0	548	1096	0	548	0	0
Sch.Recpts:	0	0	0	0	0	0	0	0	0	0	0
Net:	611	686	684	1234	0	548	1096	0	548	0	0
Plan Recpts:	611	686	684	1234	0	548	1096	0	548	0	0
Ending Inv.:	0	0	0	0	0	0	0	0	0	0	0
Ord.Release:	686	684	1234	0	548	1096	0	548	0	0	0

Total cost of ordering and inventory carrying : 6000.00

Orders to be expedited :
An order of 611 to be released in period -1 for requirement in period

press RETURN to continue.......

TABLE XII

Item code:CADP   Lead time: 1   Beginning inventory: 100
Safety stock: 25   Lot size: Fixed Order Quantity

Period:	1	2	3	4	5	6	7	8	9	10	11
Gross:	343	343	342	617	0	274	548	0	274	0	0
Sch.Recpts:	0	0	0	0	0	0	0	0	0	0	0
Net:	268	343	342	617	0	274	548	0	274	0	0
Plan Recpts:	268	800	0	800	0	0	800	0	0	0	0
Ending Inv.:	0	457	115	298	298	24	276	276	2	2	2
Ord.Release:	800	0	800	0	0	800	0	0	0	0	0

Total cost of ordering and inventory carrying : 587.50

Orders to be expedited :
An order of 268 to be released in period -1 for requirement in period

press RETURN to continue.......

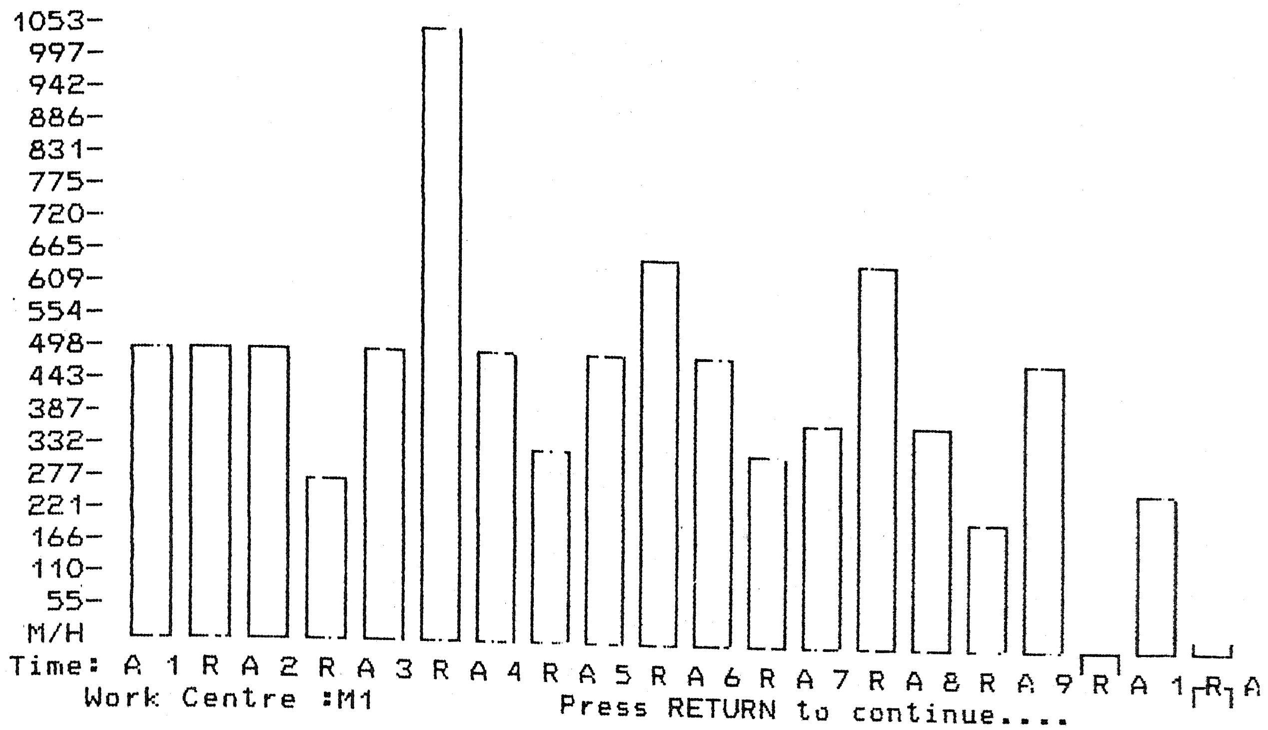

1053- 997- 942- 886- 831- 775- 720- 665- 609- 554- 498- 443- 387- 332- 277- 221- 166- 110- 55- M/H
Time: A 1 R A 2 R A 3 R A 4 R A 5 R A 6 R A 7 R A 8 R A 9 R A 1 R A
Work Centre :M1
Press RETURN to continue....

Fig A.1

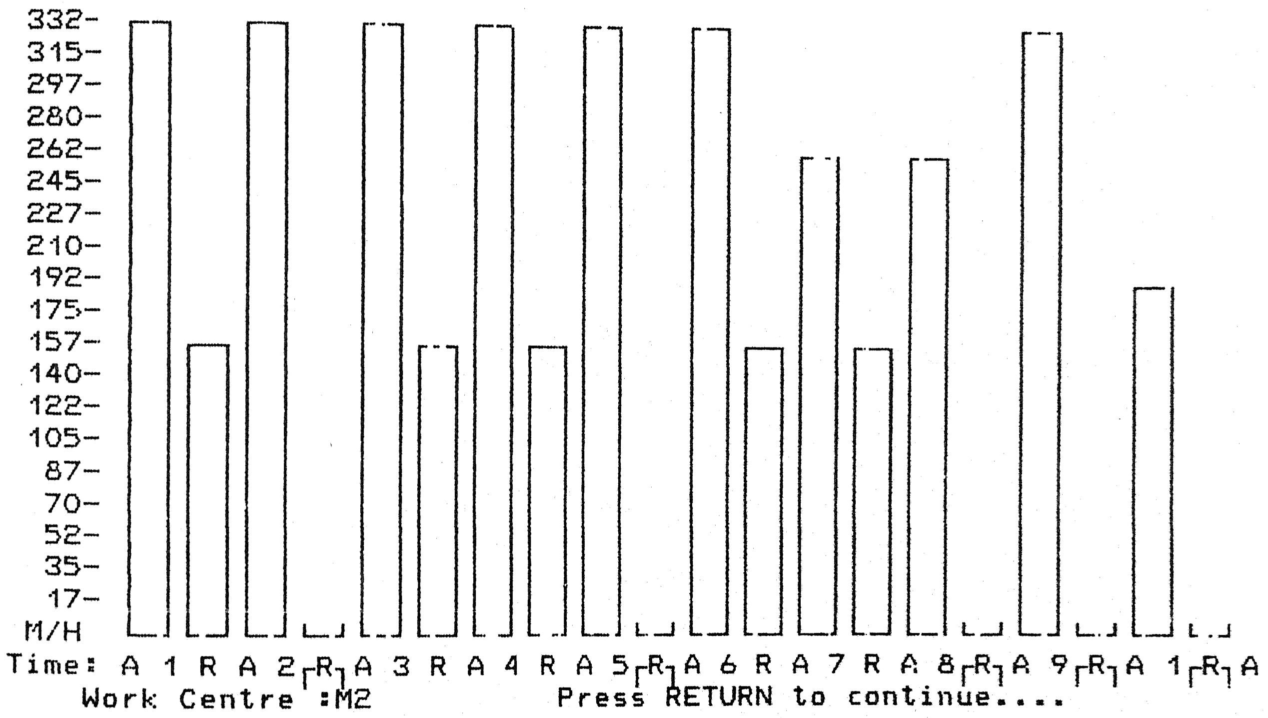

332- 315- 297- 280- 262- 245- 227- 210- 192- 175- 157- 140- 122- 105- 87- 70- 52- 35- 17- M/H
Time: A 1 R A 2 R A 3 R A 4 R A 5 R A 6 R A 7 R A 8 R A 9 R A 1 R A
Work Centre :M2
Press RETURN to continue....

Fig A 2

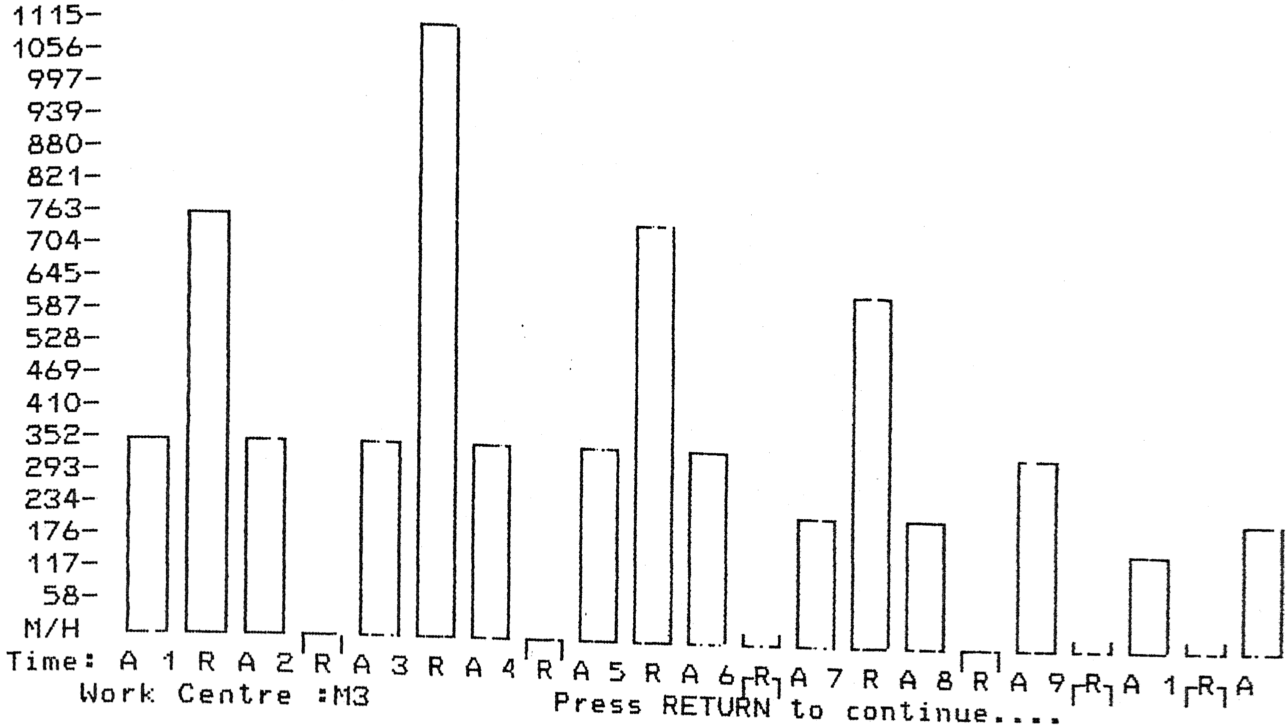

1115-
1056-
997-
939-
880-
821-
763-
704-
645-
587-
528-
469-
410-
352-
293-
234-
176-
117-
58-
M/H
Time: A 1 R A 2 R A 3 R A 4 R A 5 R A 6 R A 7 R A 8 R A 9 R A 1 R A
Work Centre :M3
Press RETURN to continue....

Fig A.3

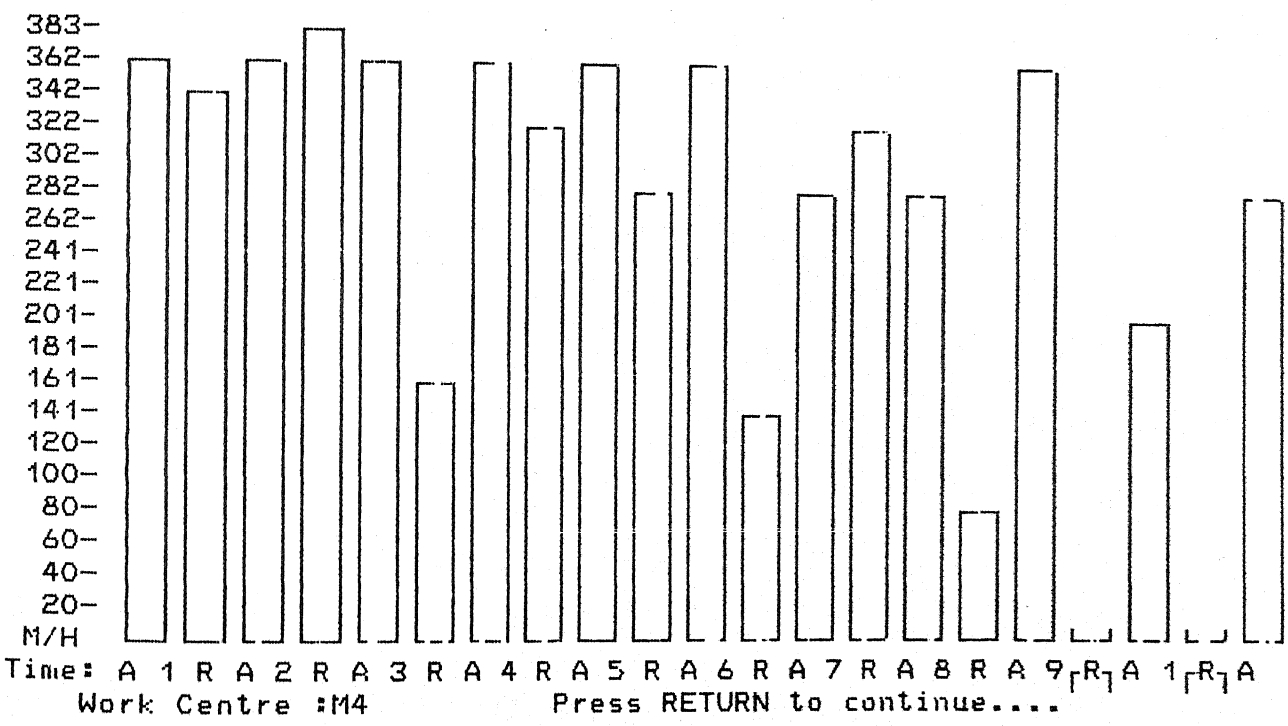

383-
362-
342-
322-
302-
282-
262-
241-
221-
201-
181-
161-
141-
120-
100-
80-
60-
40-
20-
M/H
Time: A 1 R A 2 R A 3 R A 4 R A 5 R A 6 R A 7 R A 8 R A 9 R A 1 R A
Work Centre :M4
Press RETURN to continue....

Fig A.4

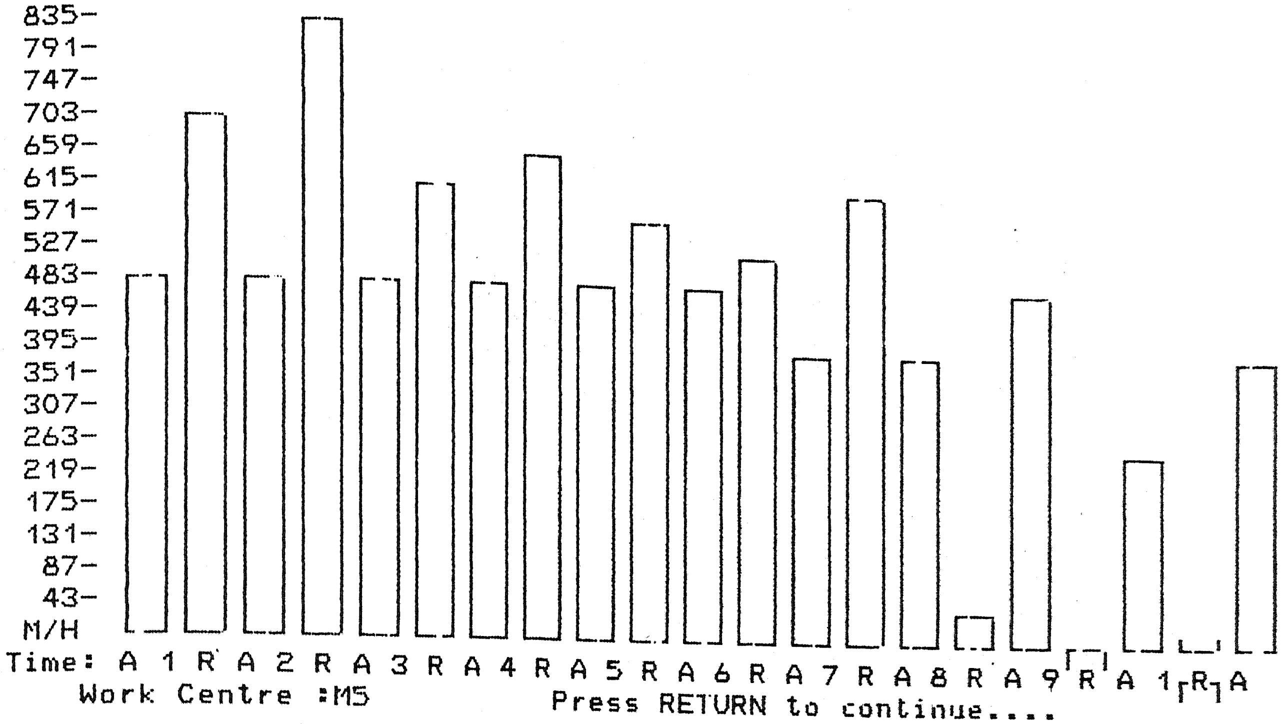

835-
791-
747-
703-
659-
615-
571-
527-
483-
439-
395-
351-
307-
263-
219-
175-
131-
87-
43-
M/H
Time: A 1 R A 2 R A 3 R A 4 R A 5 R A 6 R A 7 R A 8 R A 9 R A 1 R A
Work Centre :M5
Press RETURN to continue....

Fig A.5

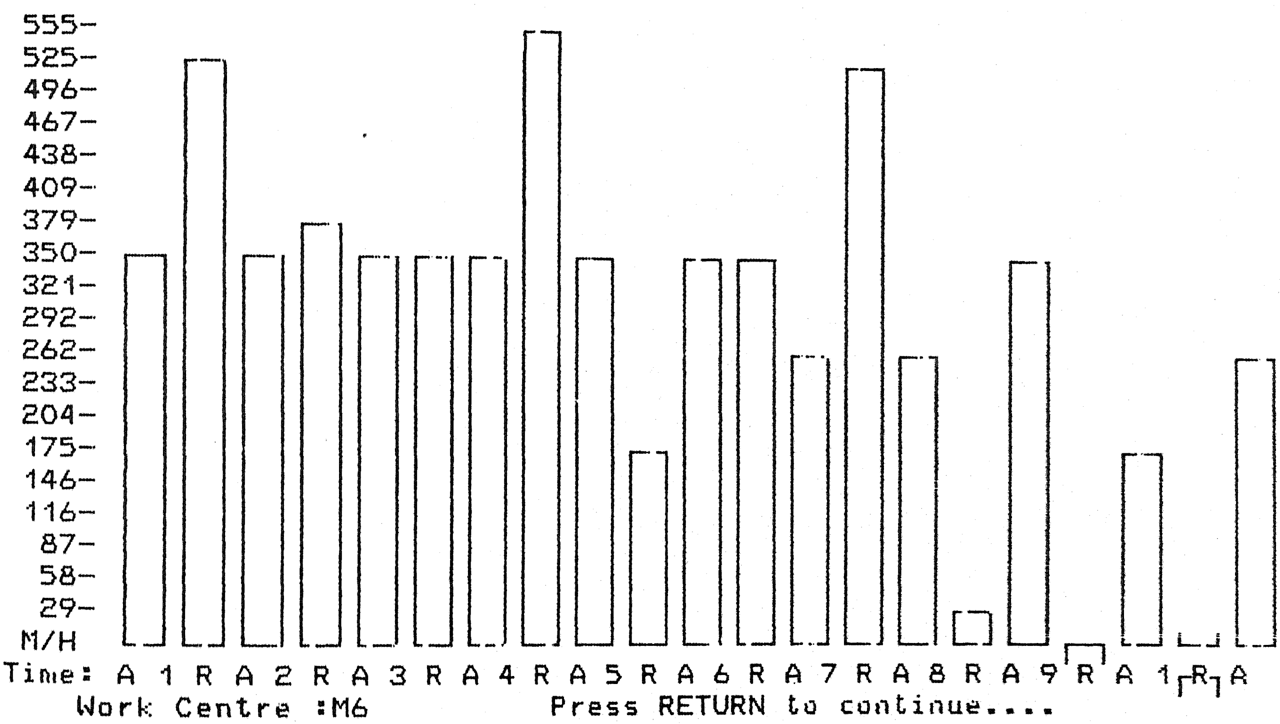

555-
525-
496-
467-
438-
409-
379-
350-
321-
292-
262-
233-
204-
175-
146-
116-
87-
58-
29-
M/H
Time: A 1 R A 2 R A 3 R A 4 R A 5 R A 6 R A 7 R A 8 R A 9 R A 1 R A
Work Centre :M6
Press RETURN to continue....

Fig A.6

PERFORMANCE REPORT :

Number of over load work centres : 5

Number of over load work centre periods : 22

Maximum over load at a work centre in a period : 2.67

Histograms of capacity plan show that capacity requirement at work centres is very much erratic, particularly at work centres M2 and M3. In some of the periods the capacity requirement is very high and in some them it is almost zero.

RESULTS OF SECOND SET OF DATA FOLLOW

TABLE XIII.

Item code:AAAE Lead time: 1 Beginning inventory: 500
Safety stock: 300 Lot size: Lot for Lot

Period:	1	2	3	4	5	6	7	8	9	10	11
Gross:	321	321	321	321	320	321	257	257	321	192	257
Sch.Recpts:	0	0	0	0	0	0	0	0	0	0	0
Net:	121	321	321	321	320	321	257	257	321	192	257
Plan Recpts:	121	321	321	321	320	321	257	257	321	192	257
Ending Inv.:	0	0	0	0	0	0	0	0	0	0	0
Ord.Release:	321	321	321	320	321	257	257	321	192	257	0

Total cost of ordering and inventory carrying : 4000.00

Orders to be expedited :
An order of 121 to be released in period -1 for requirement in

press RETURN to continue.......

TABLE XIV

Item code:AABE Lead time: 2 Beginning inventory: 600
Safety stock: 400 Lot size: Lot for Lot

Period:	1	2	3	4	5	6	7	8	9	10	11
Gross:	330	330	330	330	329	329	263	263	329	197	264
Sch.Recpts:	0	0	0	0	0	0	0	0	0	0	0
Net:	130	330	330	330	329	329	263	263	329	197	264
Plan Recpts:	130	330	330	330	329	329	263	263	329	197	264
Ending Inv.:	0	0	0	0	0	0	0	0	0	0	0
Ord.Release:	330	330	329	329	263	263	329	197	264	0	0

Total cost of ordering and inventory carrying : 4050.00

Orders to be expedited :
An order of 130 to be released in period -2 for requirement in
An order of 330 to be released in period -1 for requirement in

press RETURN to continue.......

TABLE XIX

Item code:BADS Lead time: 1 Beginning inventory: 100
Safety stock: 20 Lot size: Lot for Lot

Period:	1	2	3	4	5	6	7	8	9	10	11
Gross:	660	660	658	658	526	526	658	394	528	0	0
Sch.Recpts:	0	0	0	0	0	0	0	0	0	0	0
Net:	580	660	658	658	526	526	658	394	528	0	0
Plan Recpts:	580	660	658	658	526	526	658	394	528	0	0
Ending Inv.:	0	0	0	0	0	0	0	0	0	0	0
Ord.Release:	660	658	658	526	526	658	394	528	0	0	0

Total cost of ordering and inventory carrying : 800.00

Orders to be expedited :
An order of 580 to be released in period -1 for requirement in period

press RETURN to continue.......

TABLE XX

Item code:BAES Lead time: 1 Beginning inventory: 100
Safety stock: 50 Lot size: Lot for Lot

Period:	1	2	3	4	5	6	7	8	9	10	11
Gross:	343	343	343	342	343	274	274	343	205	274	0
Sch.Recpts:	0	0	0	0	0	0	0	0	0	0	0
Net:	293	343	343	342	343	274	274	343	205	274	0
Plan Recpts:	293	343	343	342	343	274	274	343	205	274	0
Ending Inv.:	0	0	0	0	0	0	0	0	0	0	0
Ord.Release:	343	343	342	343	274	274	343	205	274	0	0

Total cost of ordering and inventory carrying : 4500.00

Orders to be expedited :
An order of 293 to be released in period -1 for requirement in period

press RETURN to continue.......

TABLE XXI

Item code:CAAS   Lead time: 1   Beginning inventory: 100
Safety stock: 39   Lot size: Lot for Lot

Period:	1	2	3	4	5	6	7	8	9	10	11
Gross:	1663	1659	1659	1394	1395	1590	1062	1399	205	274	0
Sch.Recpts:	0	0	0	0	0	0	0	0	0	0	0
Net:	1602	1659	1659	1394	1395	1590	1062	1399	205	274	0
Plan Recpts:	1602	1659	1659	1394	1395	1590	1062	1399	205	274	0
Ending Inv.:	0	0	0	0	0	0	0	0	0	0	0
Ord.Release:	1659	1659	1394	1395	1590	1062	1399	205	274	0	0

Total cost of ordering and inventory carrying : 1350.00

Orders to be expedited :
An order of 1602 to be released in period -1 for requirement in period

press RETURN to continue.......

TABLE XXII

Item code:CABP   Lead time: 2   Beginning inventory: 100
Safety stock: 40   Lot size: Lot for Lot

Period:	1	2	3	4	5	6	7	8	9	10	11
Gross:	660	658	658	526	526	658	394	528	0	0	0
Sch.Recpts:	0	0	0	0	0	0	0	0	0	0	0
Net:	600	658	658	526	526	658	394	528	0	0	0
Plan Recpts:	600	658	658	526	526	658	394	528	0	0	0
Ending Inv.:	0	0	0	0	0	0	0	0	0	0	0
Ord.Release:	658	526	526	658	394	528	0	0	0	0	0

Total cost of ordering and inventory carrying : 3000.00

Orders to be expedited :
An order of 600 to be released in period -2 for requirement in period
An order of 658 to be released in period -1 for requirement in period

press RETURN to continue.......

TABLE XXIII

Item code:CACP Lead time: 1 Beginning inventory: 100
Safety stock: 25 Lot size: Lot for Lot

Period:	1	2	3	4	5	6	7	8	9	10	11
Gross:	686	686	684	686	548	548	686	410	548	0	0
Sch.Recpts:	0	0	0	0	0	0	0	0	0	0	0
Net:	611	686	684	686	548	548	686	410	548	0	0
Plan Recpts:	611	686	684	686	548	548	686	410	548	0	0
Ending Inv.:	0	0	0	0	0	0	0	0	0	0	0
Ord.Release:	686	684	686	548	548	686	410	548	0	0	0

Total cost of ordering and inventory carrying : 8000.00

Orders to be expedited :
An order of 611 to be released in period -1 for requirement in period

press RETURN to continue.......

TABLE XXIV

Item code:CADP Lead time: 1 Beginning inventory: 100
Safety stock: 25 Lot size: Lot for Lot

Period:	1	2	3	4	5	6	7	8	9	10	11
Gross:	343	343	342	343	274	274	343	205	274	0	0
Sch.Recpts:	0	0	0	0	0	0	0	0	0	0	0
Net:	268	343	342	343	274	274	343	205	274	0	0
Plan Recpts:	268	343	342	343	274	274	343	205	274	0	0
Ending Inv.:	0	0	0	0	0	0	0	0	0	0	0
Ord.Release:	343	342	343	274	274	343	205	274	0	0	0

Total cost of ordering and inventory carrying : 400.00

Orders to be expedited :
An order of 268 to be released in period -1 for requirement in period

press RETURN to continue.......

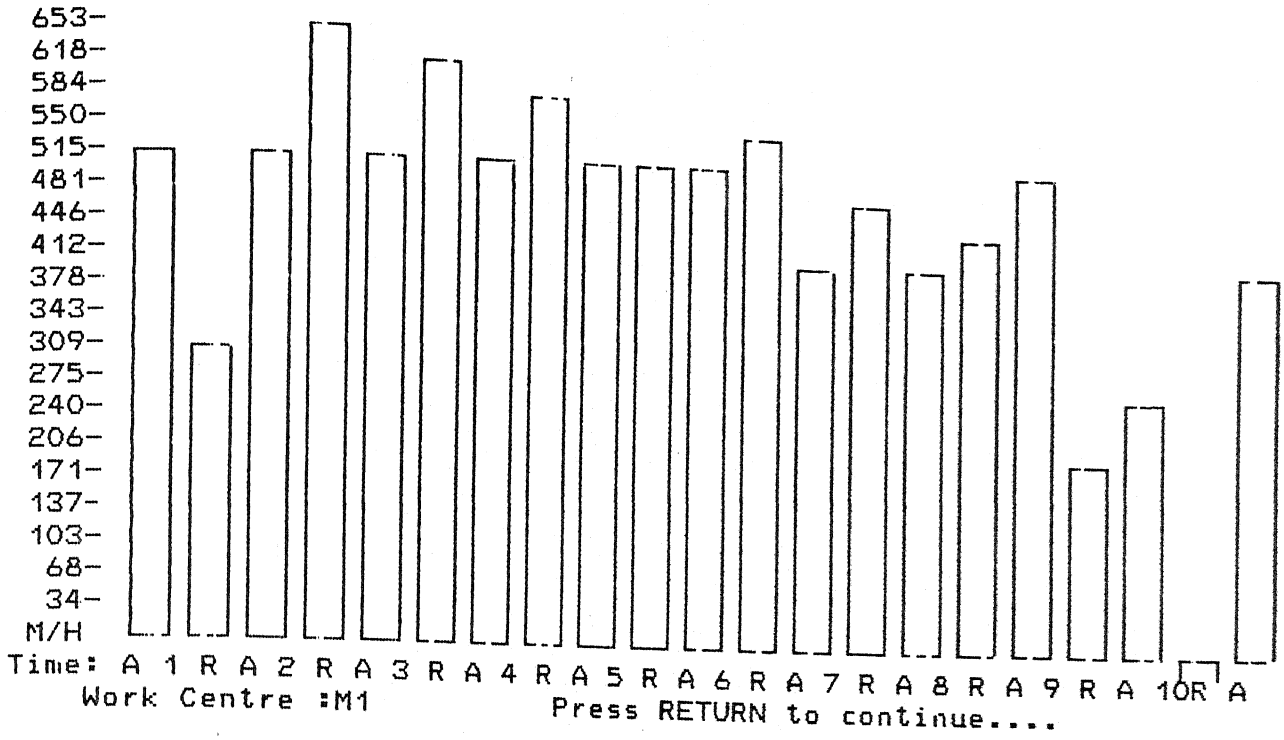

653- 618- 584- 550- 515- 481- 446- 412- 378- 343- 309- 275- 240- 206- 171- 137- 103- 68- 34-
M/H
Time: A 1 R A 2 R A 3 R A 4 R A 5 R A 6 R A 7 R A 8 R A 9 R A 10R A
Work Centre :M1
Press RETURN to continue....

Fig A7

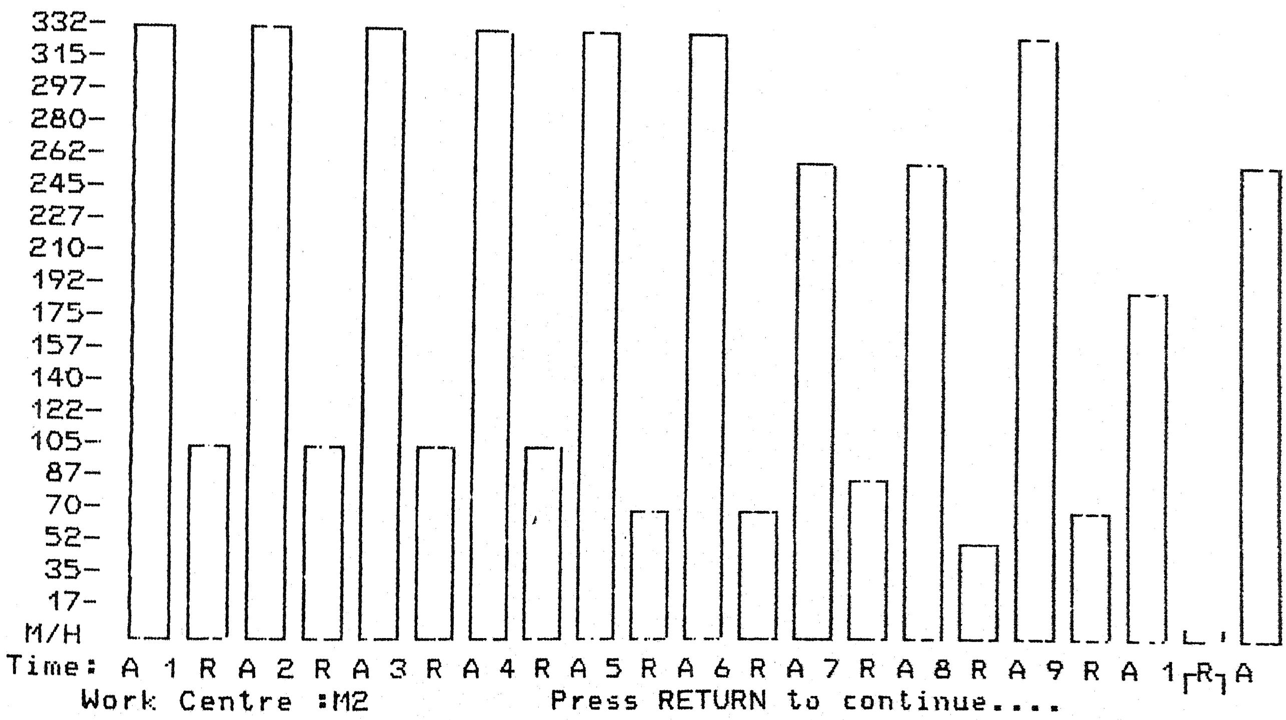

332- 315- 297- 280- 262- 245- 227- 210- 192- 175- 157- 140- 122- 105- 87- 70- 52- 35- 17-
M/H
Time: A 1 R A 2 R A 3 R A 4 R A 5 R A 6 R A 7 R A 8 R A 9 R A 1 R A
Work Centre :M2
Press RETURN to continue....

Fig A.8

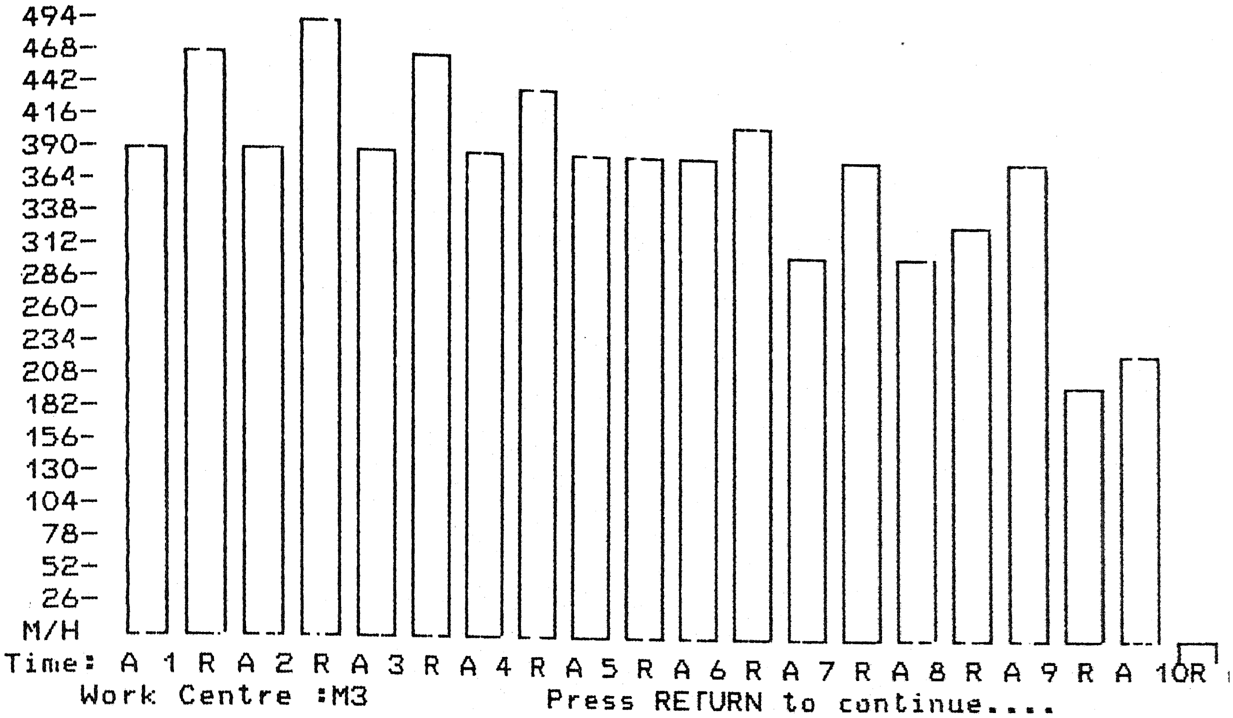


Fig A 9

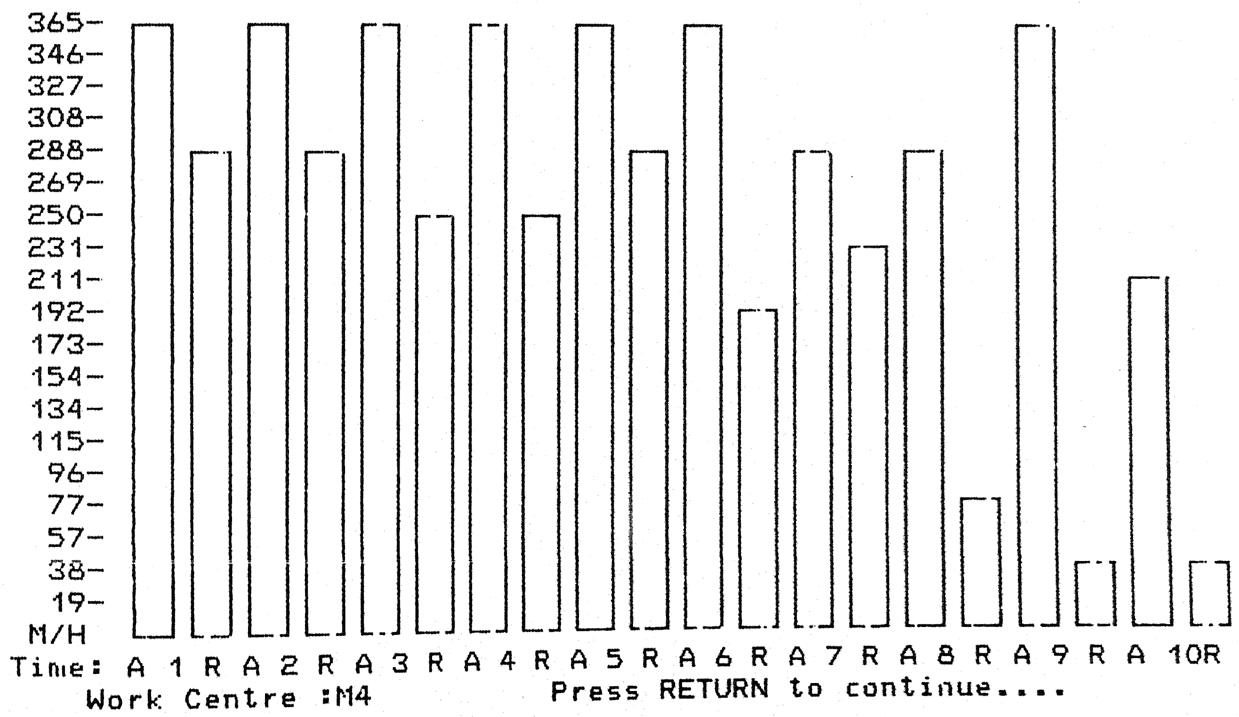


Fig A.10

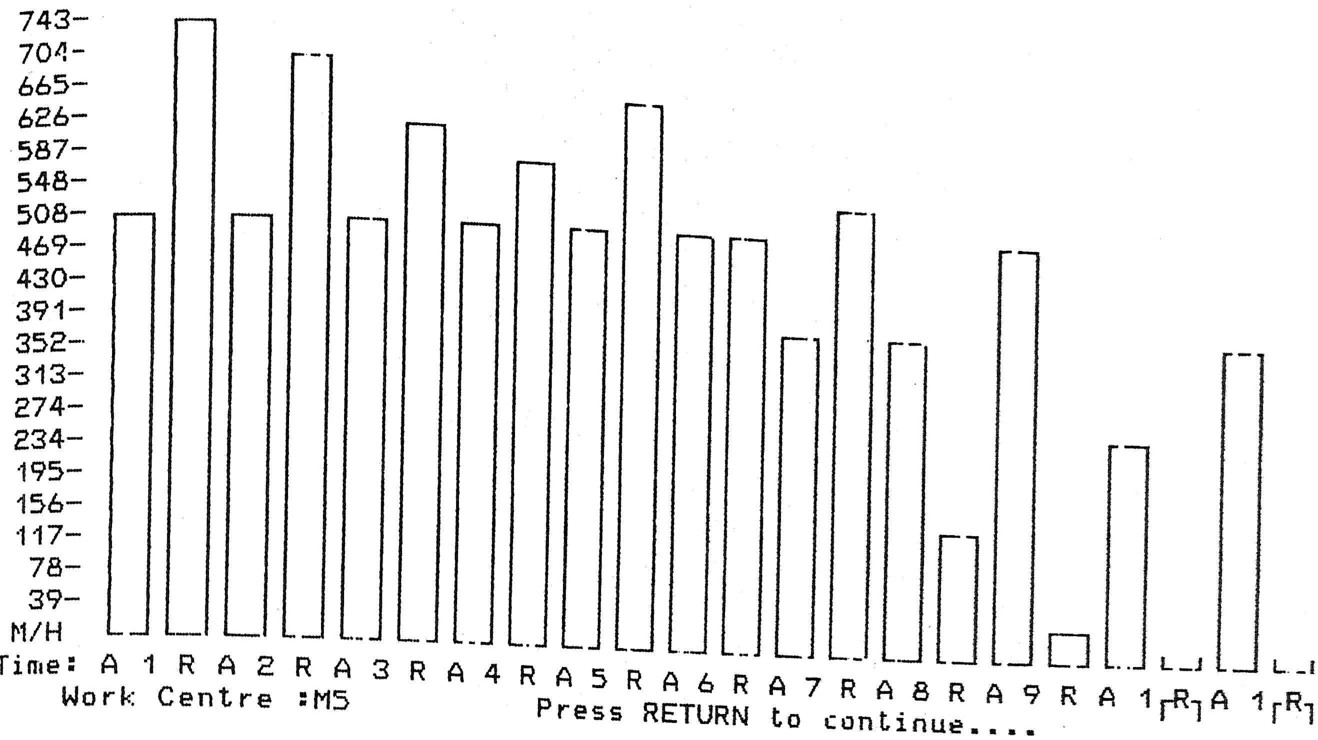


Fig A·11

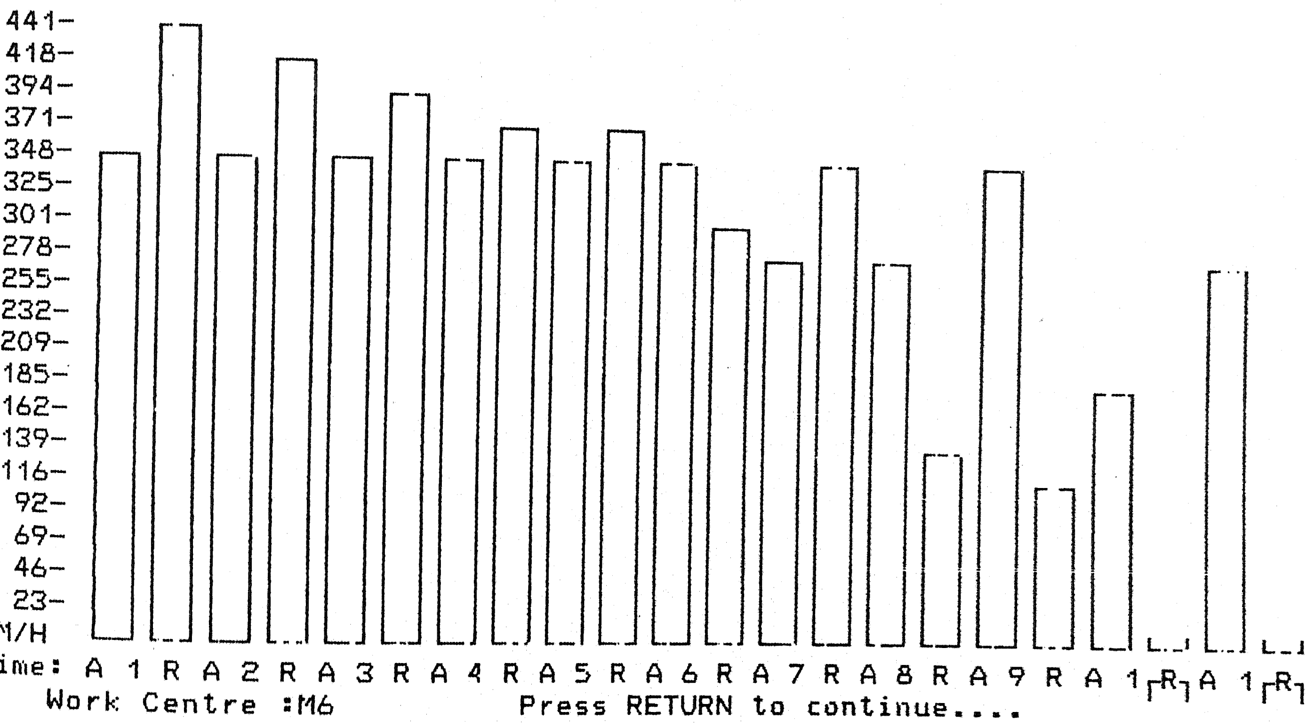


Fig A·12

Number of over load work centres : 4

Number of over load work centre periods : 27

Maximum over load at a work centre in a period : 1.40

Histograms of capacity plan show that capacity requirement work centres is very much uniform compared to that in the case

TABLE XVII

Item code:BABS Lead time: 2 Beginning inventory: 100
Safety stock: 10 Lot size: Lot for Lot

Period:	1	2	3	4	5	6	7	8	9	10	11
Gross:	1311	1311	1308	1307	1110	1046	1244	912	984	257	0
Sch.Recpts:	0	0	0	0	0	0	0	0	0	0	0
Net:	1221	1311	1308	1307	1110	1046	1244	912	984	257	0
Plan Recpts:	1221	1311	1308	1307	1110	1046	1244	912	984	257	0
Ending Inv.:	0	0	0	0	0	0	0	0	0	0	0
Ord.Release:	1308	1307	1110	1046	1244	912	984	257	0	0	0

Total cost of ordering and inventory carrying : 10000.00

Orders to be expedited :
An order of 1221 to be released in period -2 for requirement in period
An order of 1311 to be released in period -1 for requirement in period

press RETURN to continue.......

TABLE XIII

Item code:BACS Lead time: 1 Beginning inventory: 100
Safety stock: 7 Lot size: Lot for Lot

Period:	1	2	3	4	5	6	7	8	9	10	11
Gross:	642	642	642	640	642	514	514	642	384	514	0
Sch.Recpts:	0	0	0	0	0	0	0	0	0	0	0
Net:	549	642	642	640	642	514	514	642	384	514	0
Plan Recpts:	549	642	642	640	642	514	514	642	384	514	0
Ending Inv.:	0	0	0	0	0	0	0	0	0	0	0
Ord.Release:	642	642	640	642	514	514	642	384	514	0	0

Total cost of ordering and inventory carrying : 450.00

Orders to be expedited :
An order of 549 to be released in period -1 for requirement in period

press RETURN to continue.......

1. The capacity of the work centres is considered inflexible except overtime work.

2. The resources are not transferable from one work centre to the other.

4. Back orders are not allowed.

5. Machine setup is sequence independent at all work centres.

6. Lead times for production of components and procurement of materials are considered deterministic.

7. Overtime work is allowed to meet the capacity requirement at the short term capacity requirement planning level. It is not considered while preparing MPS at strategic level.

3.3 Overview Of MPS Preparation Procedure:

The procedure followed for the development of capacity constrained MPS (CCMPS) for the system under consideration is shown in Fig 3.1.

The basic input required for the preparation of the MPS are the demands or requirements of each end item in each period of the planning horizon, resources available, product structure of each product and resource profile for all components and end items. Product structure is structured list of all materials or parts needed to produce a particular finished product, sub-assembly, manufactured part or purchased part. Each item/component inputted into the system is coded using low level coding system discussed in section 4.6. Resource profile is the time phased requirements of the resources by an item/component over its lead time.

Final Schedule :

A_{jk}	150	150	150	150	215	100	100	150

This is the perspective MPS for product j and is fed as an input for Rough Cut Capacity Planning.

3.7 Rough Cut Capacity Planning

The aim of rough cut capacity planning is to test the availability of critical machine resources for the desired production and adjust the production so as to make it feasible with in the given amount of resources. The critical machines are those which may cause bottleneck problems on the shopfloor. The proposed methodology is based on the work of Sadowski et al.[14] which has been extended to include Priority Rule for selecting the product and the amount of its production to be reduced to make the overall production feasible.

3.7.1 Model Rationale And Assumptions:

The methodology used is intended for manufacturing environment with well defined and stable product line.

All times are provided in terms of the machine requirements for the end product. For example, if a set of machines produces four parts which are all assembled together to make one end product, then the time requirement for that machine for that end product is stated as sum of the times to produce the four individual parts. These times are also adjusted to account for more than one part required per end product.

3.8.3.2 Gross Requirements :

This is the quantity of the item that will have to be issued to support a parent order. An end item is subjected to only independent demand and hence the MPS will give the gross requirements for that item. Any other item may be subjected to dependent demand from one or several parent items that use it in common, and it may also be subjected to independent demand generating from sources external to the plant. The gross requirement for this item will be the sum of dependent demand from all its parents and the independent demand.

3.8.3.3 Scheduled Receipts :

These represent the material on order scheduled to arrive in the future periods.

3.8.3.4 Net Requirements :

Net requirements are developed by allocating quantities in inventory to the quantities of gross requirements, in a level-by-level process.

Net requirement = Gross requirement - Scheduled receipt - on hand quantity

If the result obtained by the above formula is negative, the net requirement is zero.

3.8.3.5 Coverage of Net Requirements:

In an MRP system, the net requirements are to be covered by planned orders i.e. new orders for the respective item scheduled for release in the future. To generate a planned order, the system must determine the following.

intermediate stage to the lower decision systems. For processing MRP logic the regenerative MRP method is used. That is, it recalculates the whole material plan each time, it is run. For quickly evaluating the performance of the system the facility of plotting the histogram of capacity plan for each work centre i.e capacity available Vs. capacity required, has been provided. Shop loading factor, and lot sizing technique selected for each item/component can be changed to develop various MPS and the corresponding capacity utilisation. The various performance parameters, namely, number of overload work centres, total number of overload work centre periods and maximum overall overload can be used to evaluate alternate strategies.

4.3 Database Design Issues:

The basic design issues involved are: quick accessability, minimum repetition of data, file integrity, size of the data file, i.e. the number of fields in a record and number of files used. Quick accessability of data makes the operation of data searching fast. Minimum data repetition saves space for data storage. Validity and integrity of data is also maintained by minimum repetition of data, because if a piece of data is changed then it has to be changed in all the records where it is stored and this process is prone to mistake. In the present work the database has been normalized to third normal form. Data in a records is accessed through key fields and various files are linked together on foreign key fields to search the data from more than one file. The size of the file should not be too large i.e, it should not

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7. Bellington P., McClain J., and Thomas J., "The Interaction of Lead Time Determination , Lot Size Decision and Capacity Planning in MRP System", Proceedings American Institute of Decision Science, Eleventh Annual Meeting, 1979.

8. Carlson R.C., Backman S.L., and Kropp D.H., "Less Nervous System : A Dynamic Economic Lot Sizing Approach, Management Science , Vol 25 , 1979.

Change in the Capacity Of Work Centres :

Capacity of no work centre is changed.

Calculation Of Effective Capacity With Available Resources:

The feasible production targets for each product is set as follows:

Product	Target Production Level
X01	1479
X02	1517
X03	1578

Production Levelling Process:

Levelled production for each product is obtained as follows.

Pespective M P S

	Product		
Period	X01	X02	X03
1	1479	1517	1578
2	1479	1517	1578
3	1767	1517	1578
4	1600	1517	1578
5	1500	1517	1578
6	1452	1517	1626
7	1428	1541	1578
8	1478	1865	1929

TABLE VII

Item code:BADS Lead time: 1 Beginning inventory: 100
Safety stock: 20 Lot size: Least Unit Cost

Period:	1	2	3	4	5	6	7	8	9	10	11
Gross:	660	660	658	658	526	526	658	394	528	0	0
Sch.Recpts:	0	0	0	0	0	0	0	0	0	0	0
Net:	580	660	658	658	526	526	658	394	528	0	0
Plan Recpts:	580	660	658	658	526	526	658	394	528	0	0
Ending Inv.:	0	0	0	0	0	0	0	0	0	0	0
Ord.Release:	660	658	658	526	526	658	394	528	0	0	0

Total cost of ordering and inventory carrying : 800.00

Orders to be expedited :
An order of 580 to be released in period -1 for requirement in period

press RETURN to continue.......

TABLE VIII

Item code:BAES Lead time: 1 Beginning inventory: 100
Safety stock: 50 Lot size: Modified LTC

Period:	1	2	3	4	5	6	7	8	9	10	11
Gross:	343	343	343	342	343	274	274	343	205	274	0
Sch.Recpts:	0	0	0	0	0	0	0	0	0	0	0
Net:	293	343	343	342	343	274	274	343	205	274	0
Plan Recpts:	293	343	343	342	617	0	274	548	0	274	0
Ending Inv.:	0	0	0	0	274	0	0	205	0	0	0
Ord.Release:	343	343	342	617	0	274	548	0	274	0	0

Total cost of ordering and inventory carrying : 4218.50

Orders to be expedited :
An order of 293 to be released in period -1 for requirement in period 1

press RETURN to continue.......